Nathan Leisso - NEON (now Ball Aerospace)
Joe Boardman - AIG
Tristan Goulden - NEON
Ian Crocker - NEON

Calibration of NEON's Spectrometers

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A project sponsored by the National Science Foundation and proudly operated by Battelle

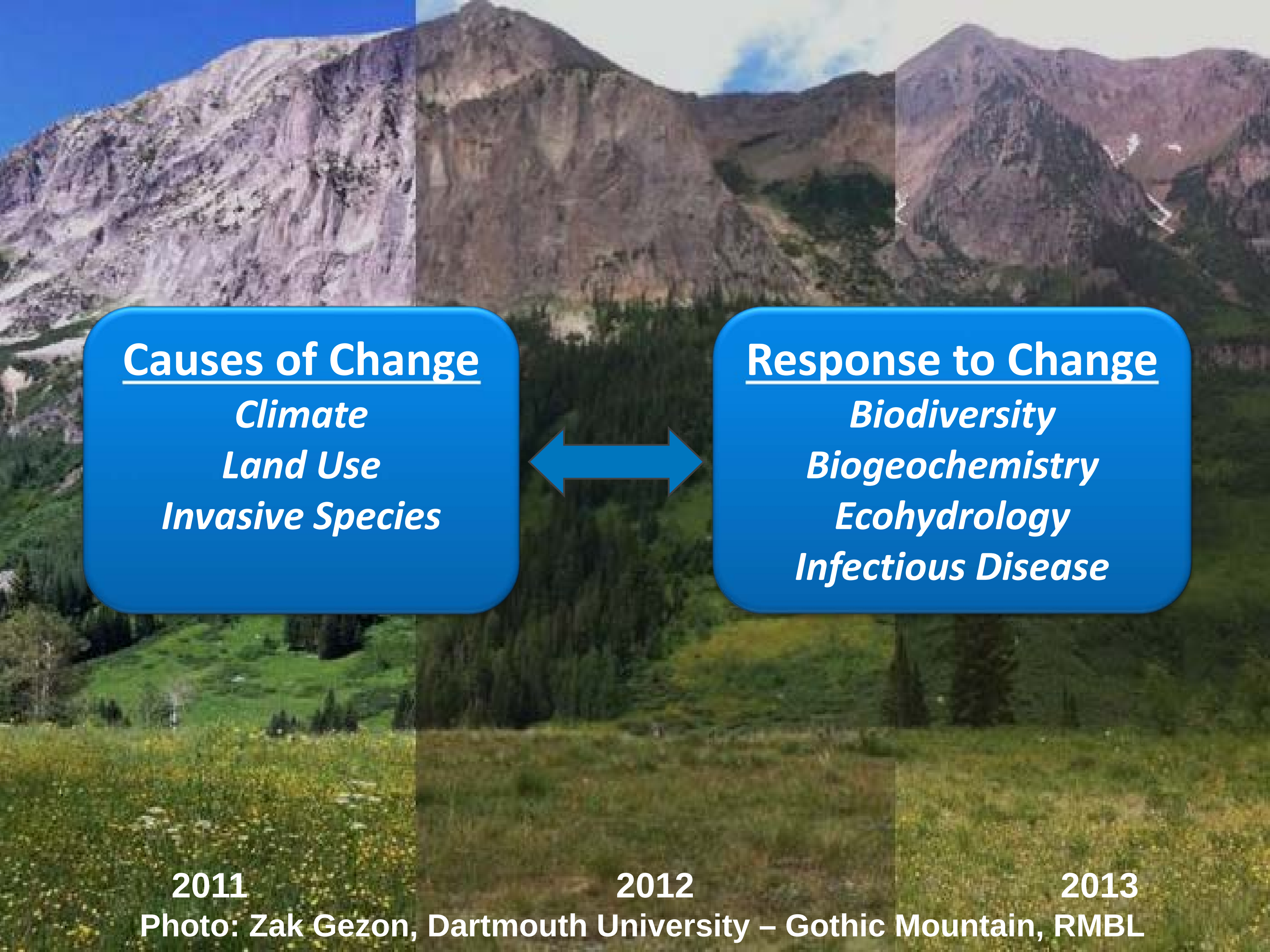
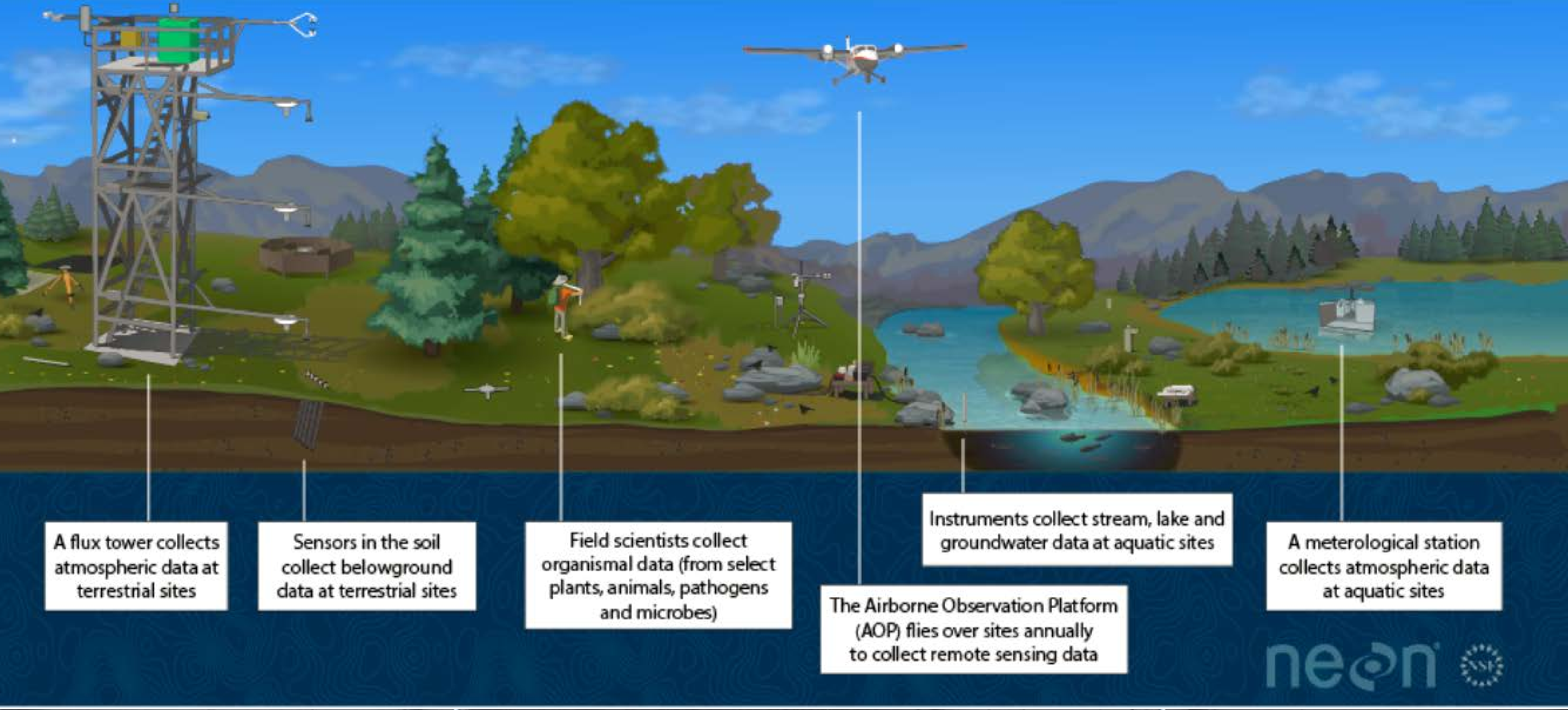


Photo: Zak Gezon, Dartmouth University – Gothic Mountain, RMBL

NEON Collection Challenges

National Ecological Observatory Network


A flux tower collects atmospheric data at terrestrial sites
Sensors in the soil collect belowground data at terrestrial sites
Field scientists collect organismal data (from select plants, animals, pathogens and microbes)
The Airborne Observation Platform (AOP) flies over sites annually to collect remote sensing data
Instruments collect stream, lake and groundwater data at aquatic sites
A meterological station collects atmospheric data at aquatic sites
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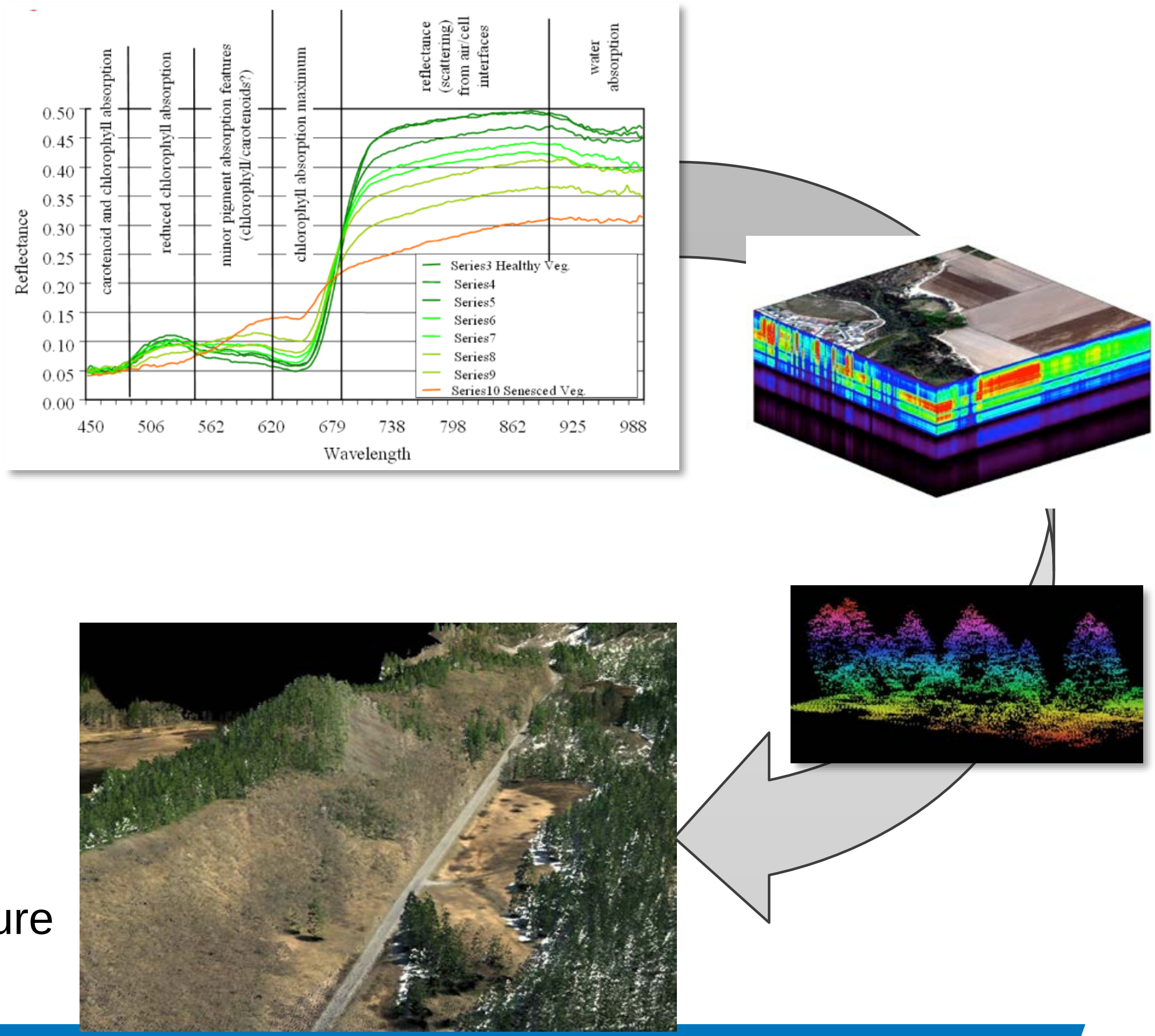
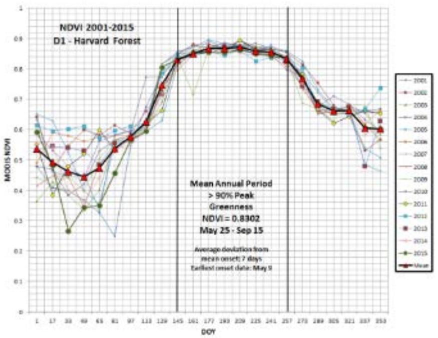
Why use hyperspectral + LiDAR to study ecosystems?

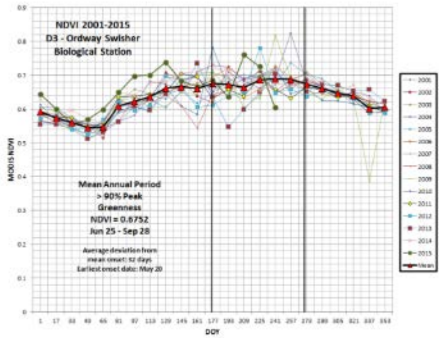
Fusing hyperspectral and LiDAR data has long been recognized as a valuable tool for studying ecosystems

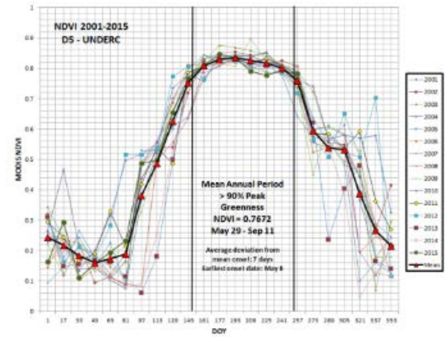
- Imaging Spectrometer
  - Vegetation health
  - Vegetation type
- LiDAR
  - Surface topography
  - Canopy height & structure

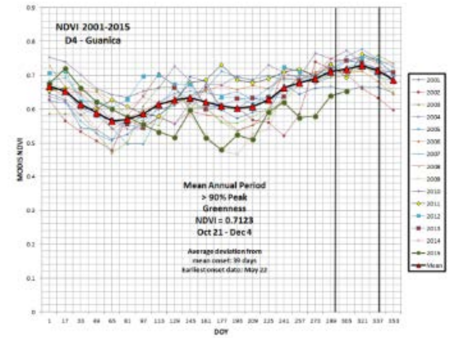


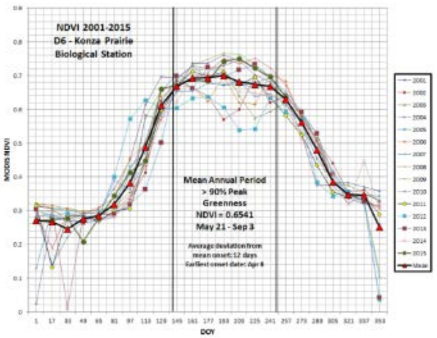
Airborne Survey Scheduling Constraints - Phenology

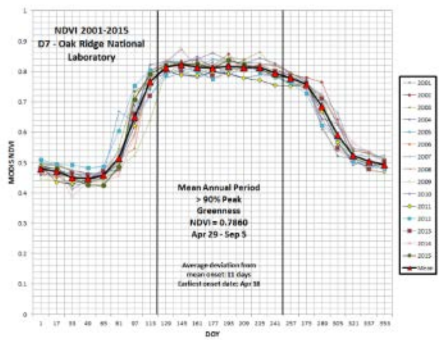


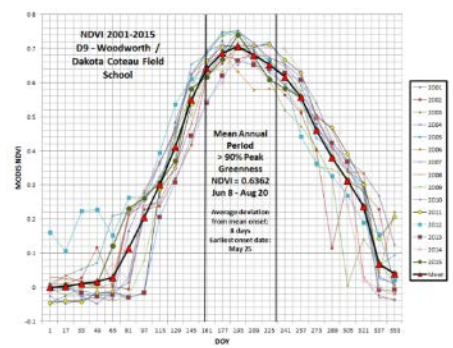


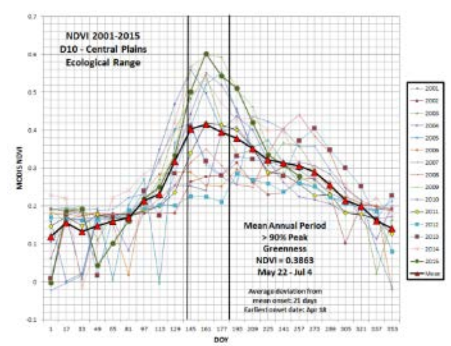


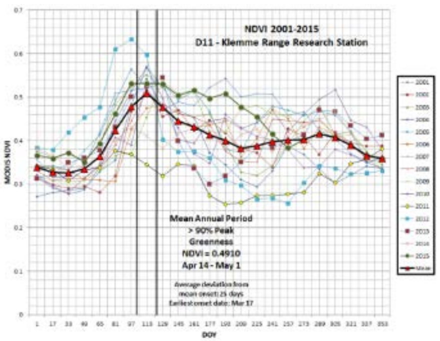


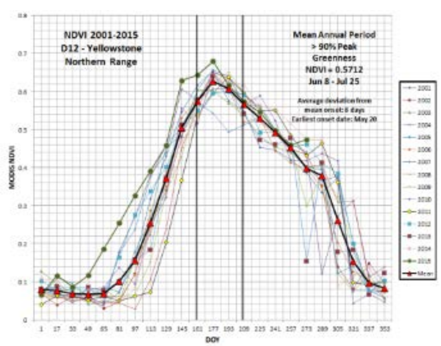


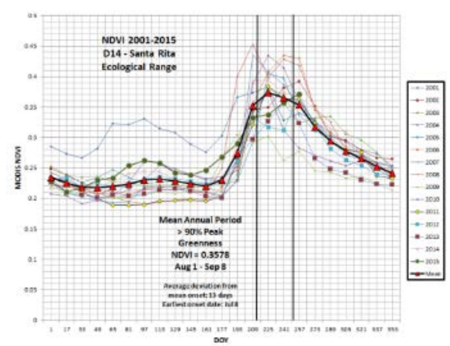


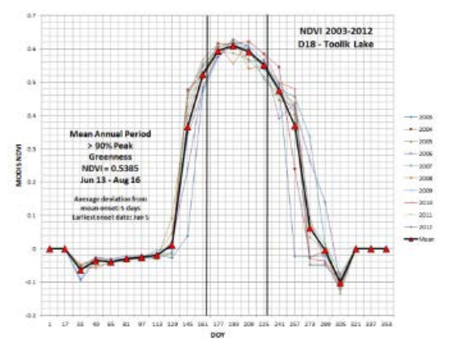




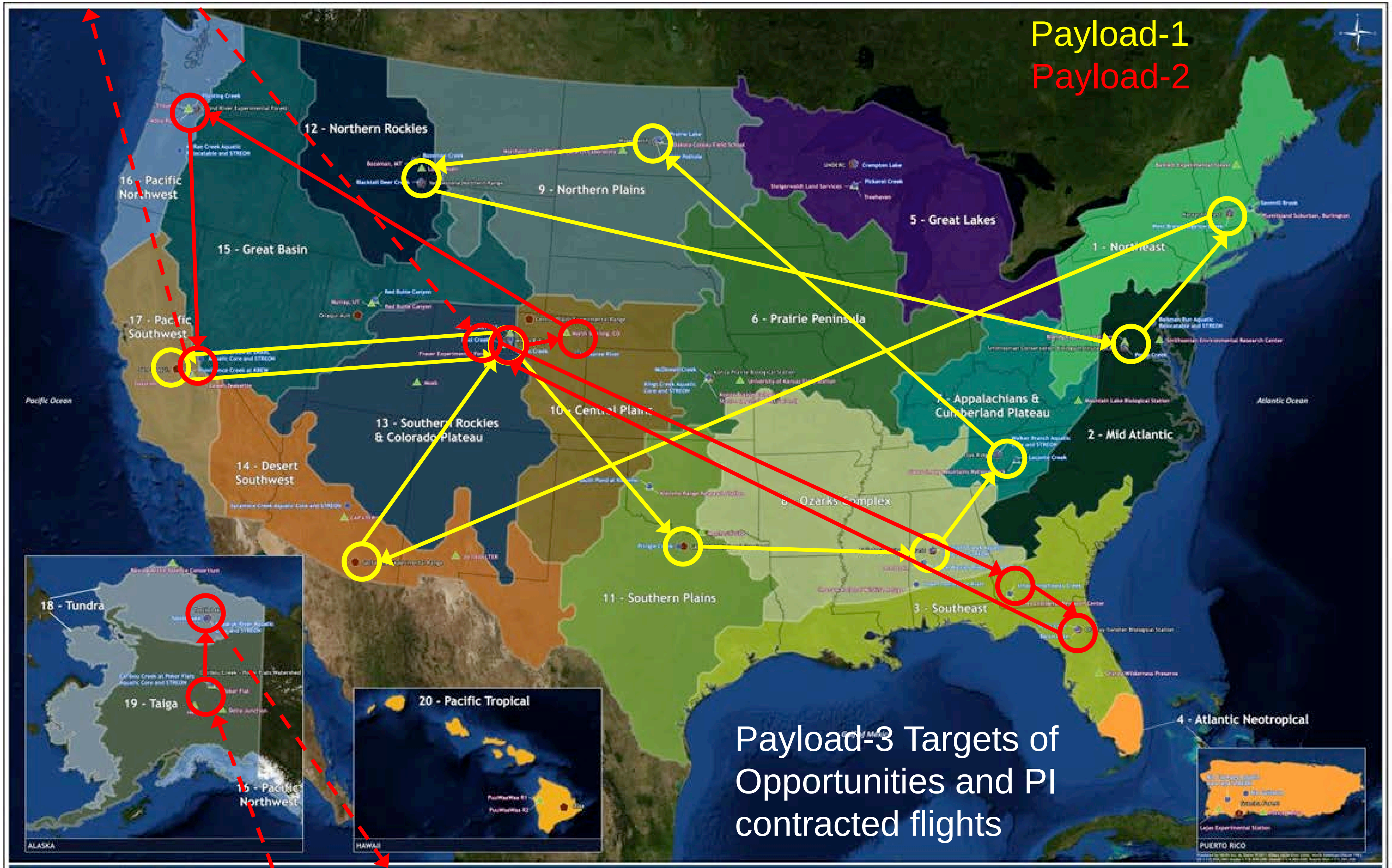








NEON AOP 2018 Proposed Flight Schedule



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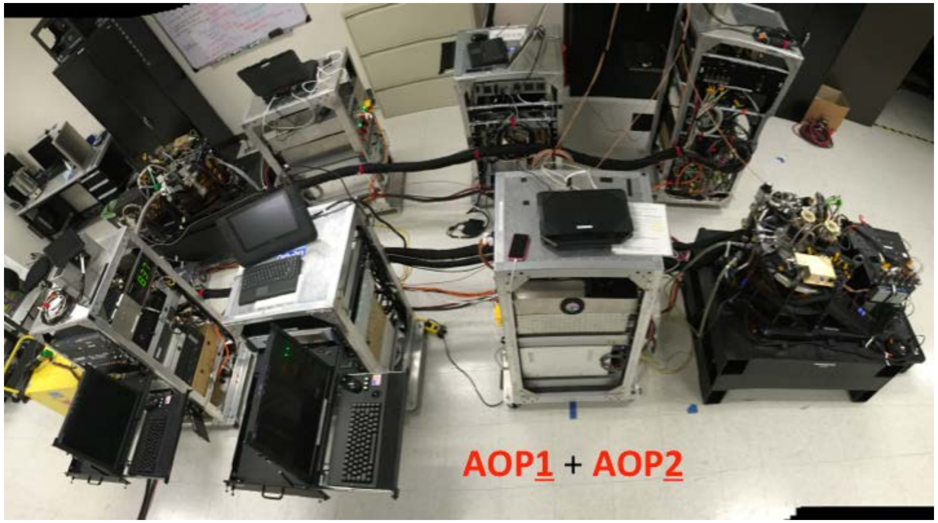
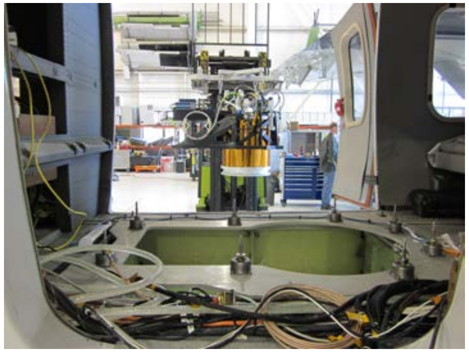
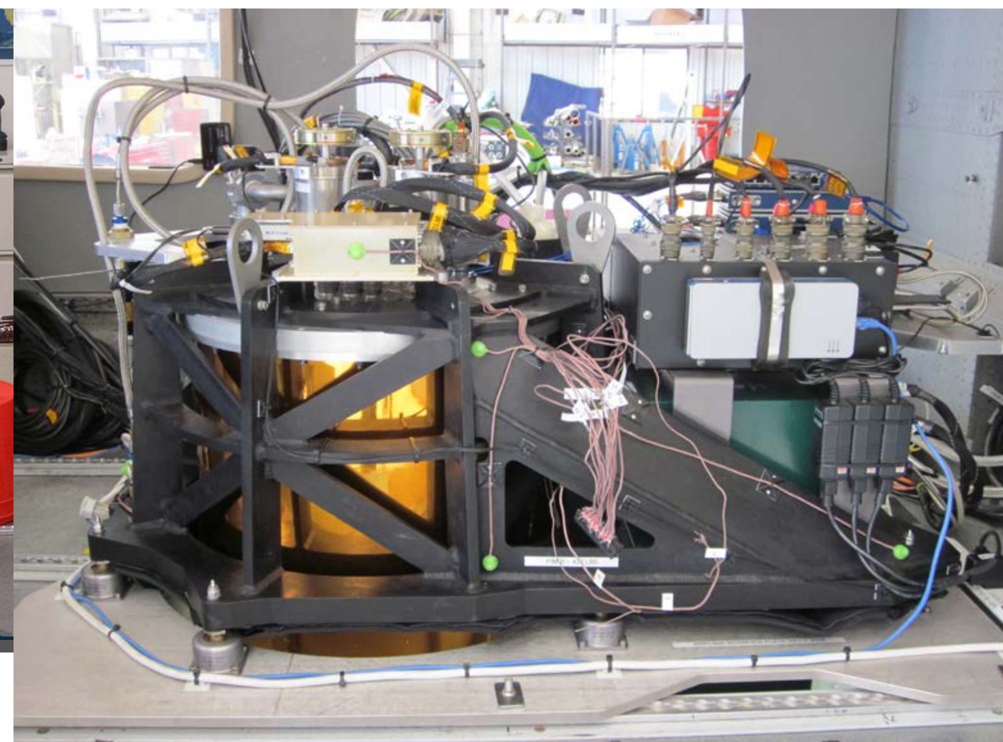
NEON AOP Flight Operations





AOP Payload Sensor and Support Infrastructure

- Nominal Payload includes three main sensors:
  - **NEON Imaging Spectrometer (NIS)**: Custom instrument from JPL
  - **Waveform Lidar**: COTS system from Teledyne Optech or Riegl
  - **Digital Camera**: COTS system from Teledyne Optech or Riegl
- AOP has integrated these into a custom payload with required support infrastructure

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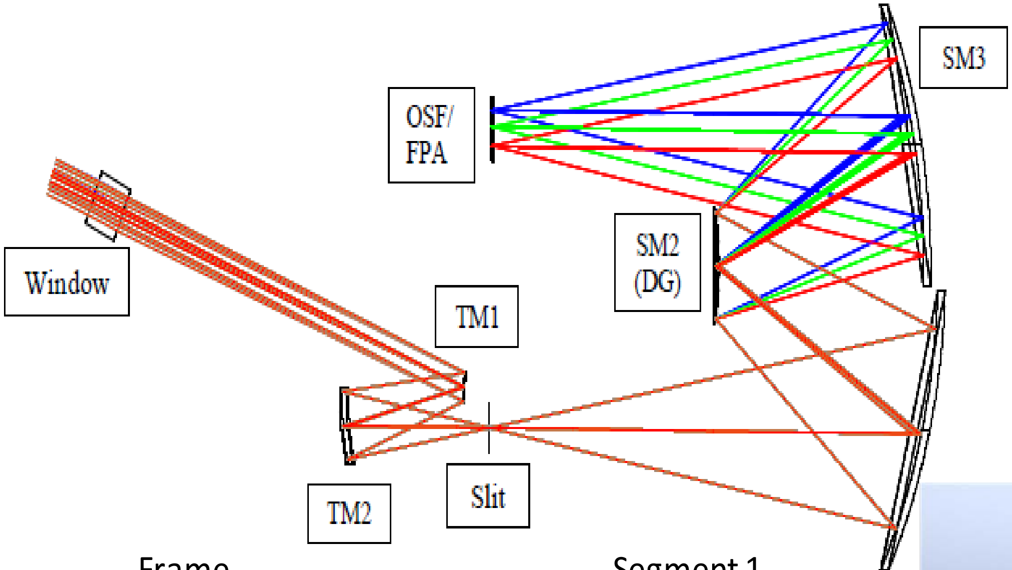
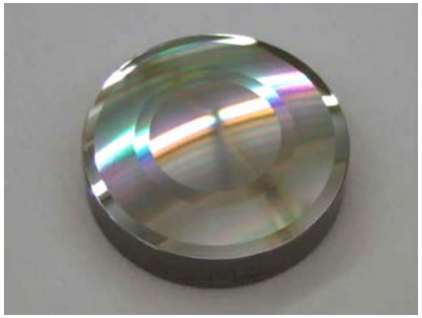
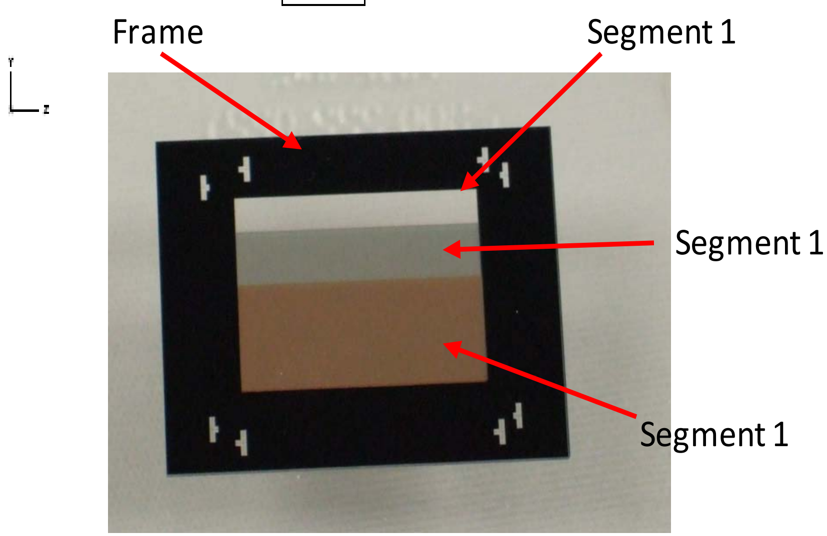
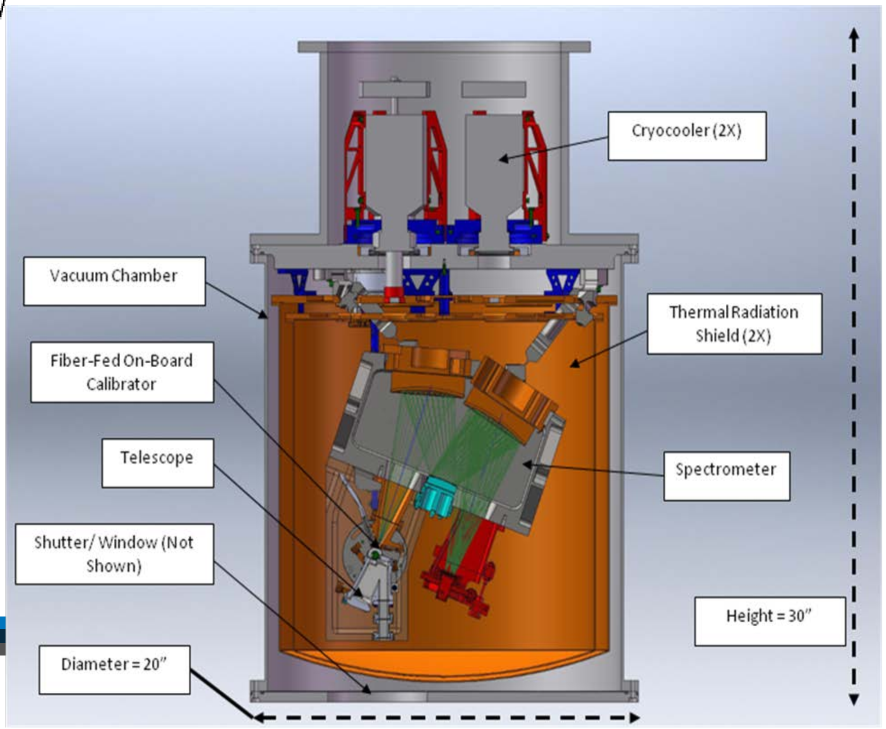
NEON Imaging Spectrometer



Convex Diffraction Grating







NIS Raw Flight Line Sequence

NIS Shuttered, 1000 Frames of Dark Offset

NIS Shuttered, 1000 Frames of Dim OBC

NIS Shuttered, 1000 Frames of Bright OBC

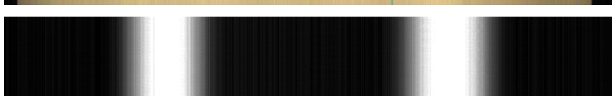
NIS Shuttered, 500 Frames of SOBC (HeNe@632.8-nm)

NIS Science collect, 10461 raw science frames in this particular flightline (5000 to 60000 typical), ~300 in image shown.

NIS Shuttered, 1000 Frames of Dark Offset

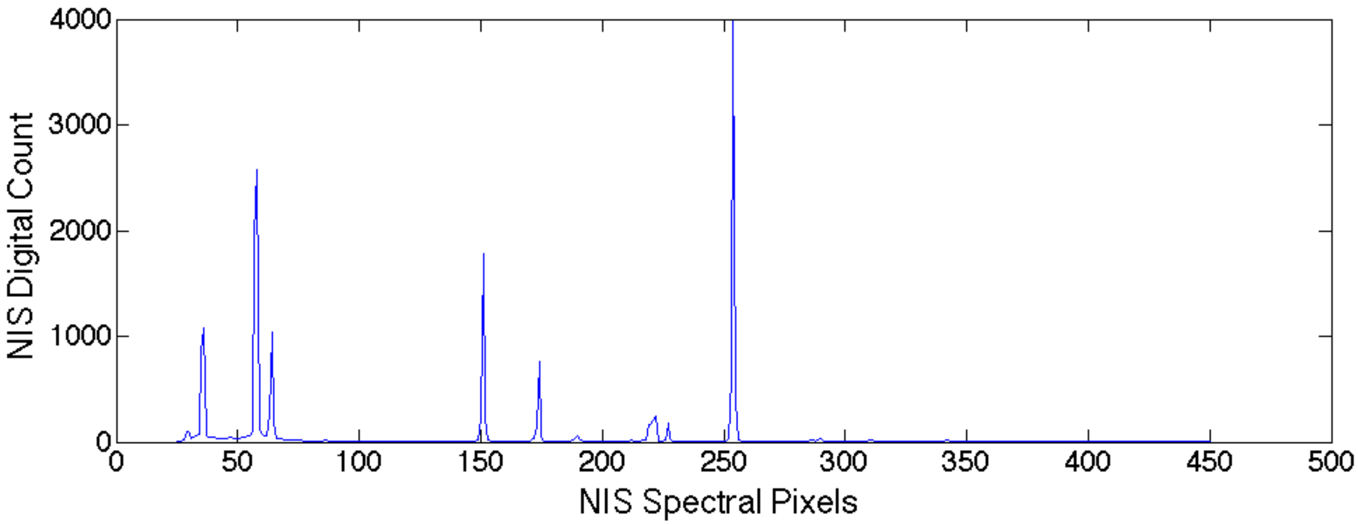
NIS Shuttered, 1000 Frames of Dim OBC

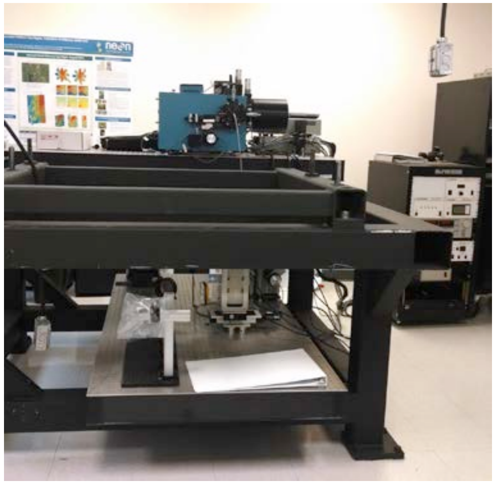
NIS Shuttered, 1000 Frames of Bright OBC

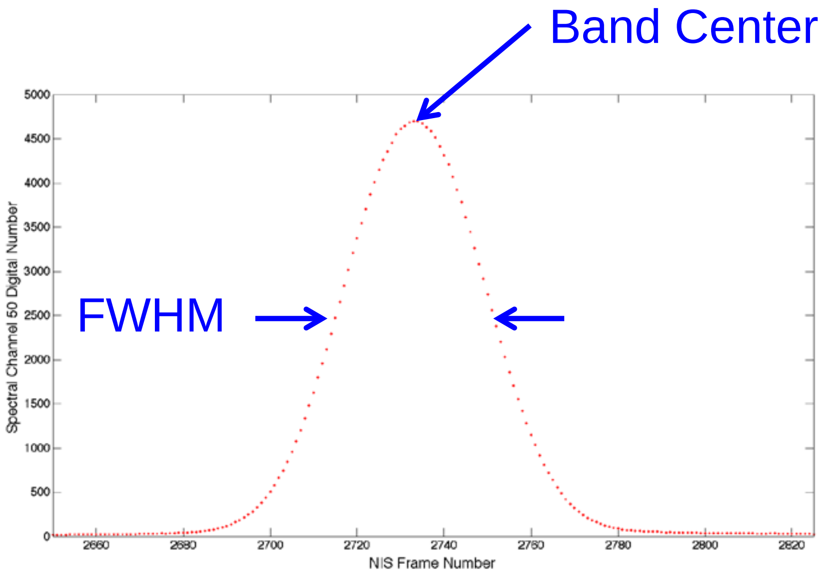


NIS Shuttered, 1000 Frames of SOBC (HeNe@632.8-nm)

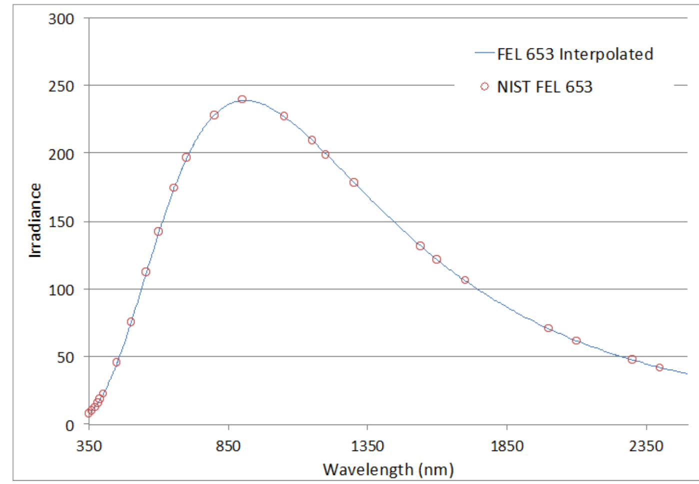
Spectral Calibration

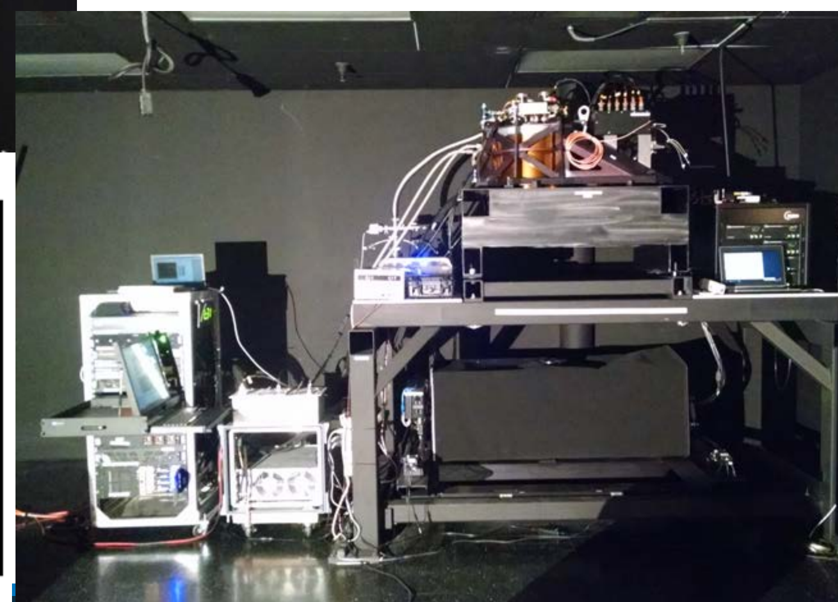


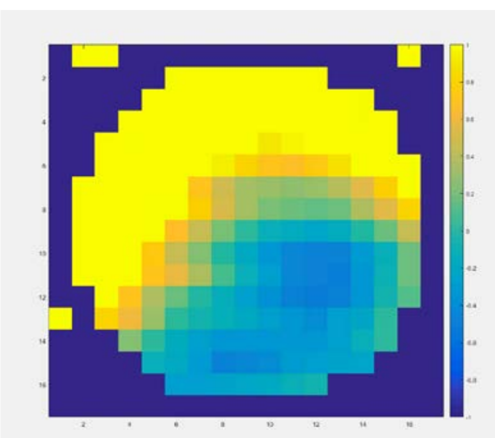


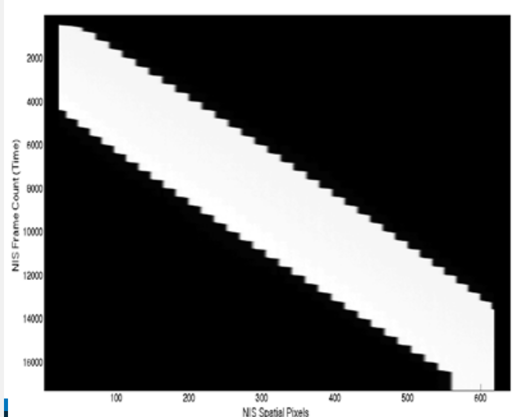


Radiometric Calibration

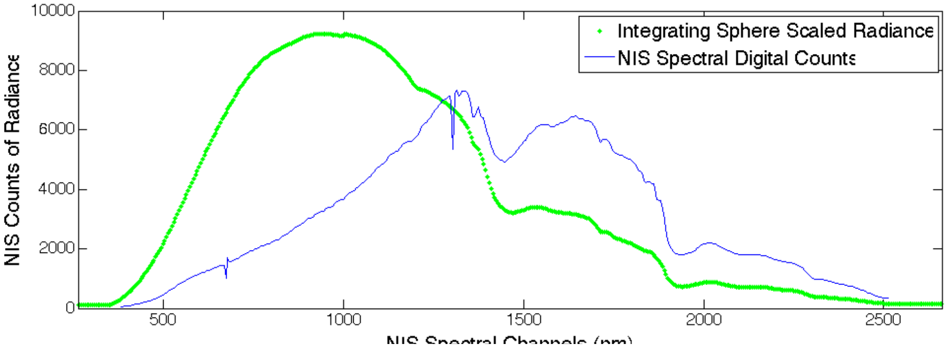


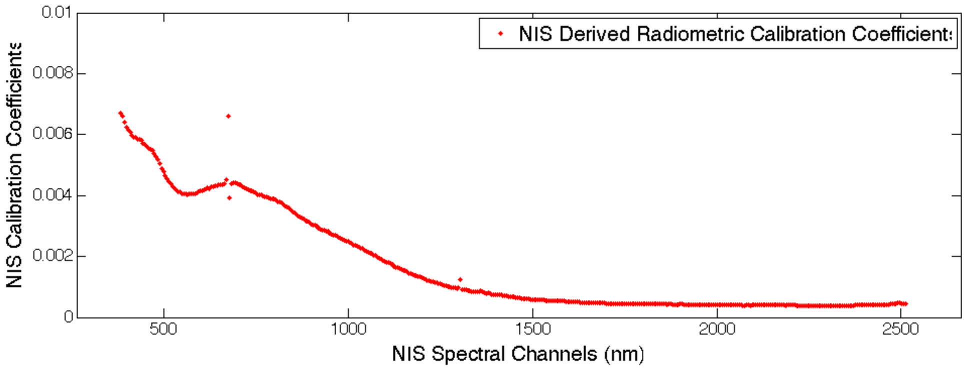


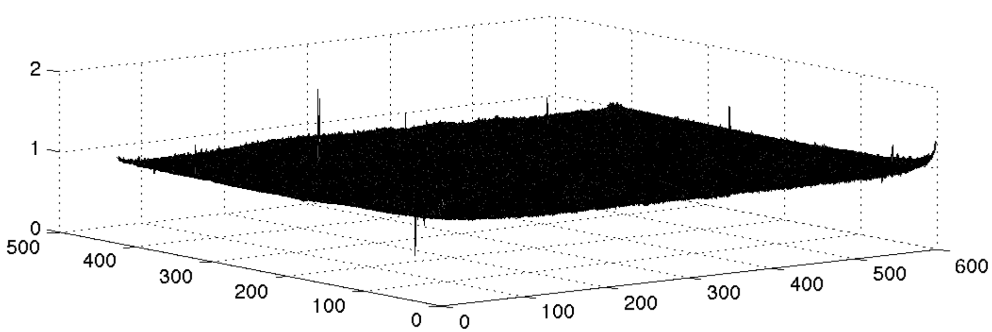


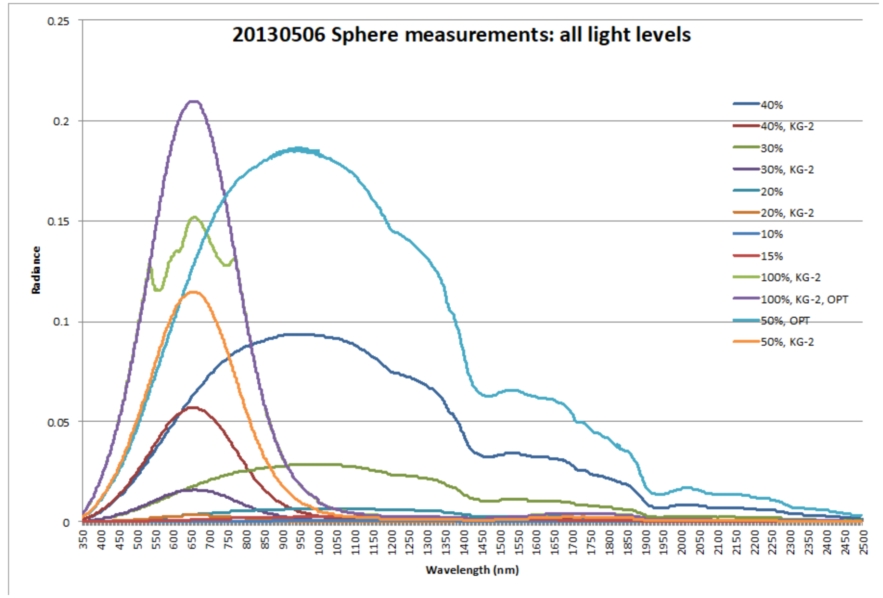


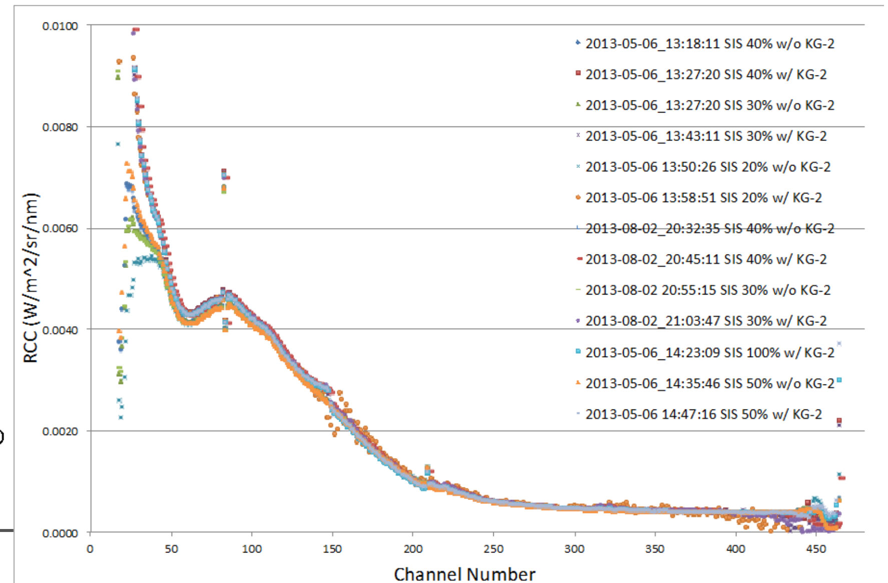
Radiometric Calibration











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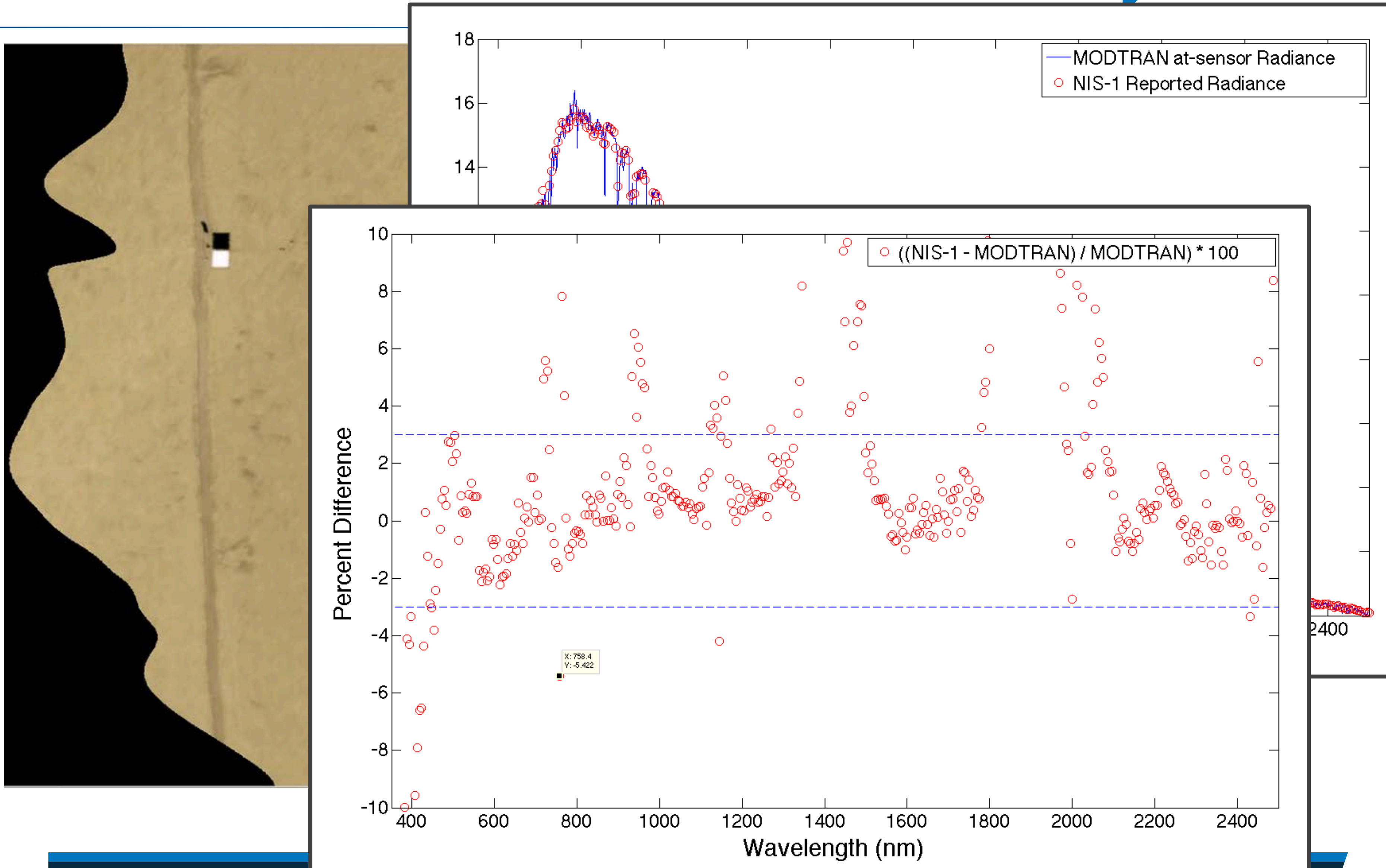
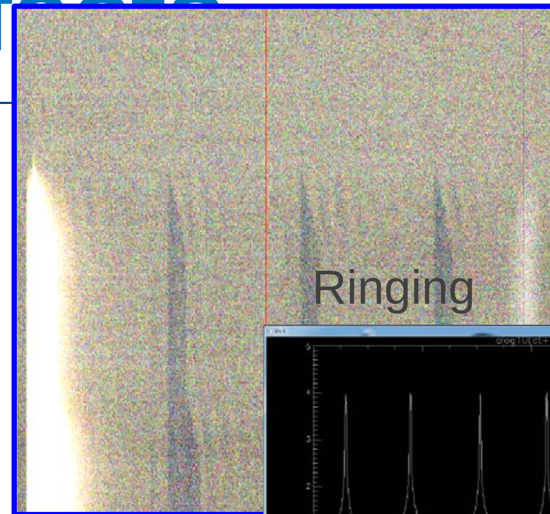
Vicarious Calibration at Railroad Valley

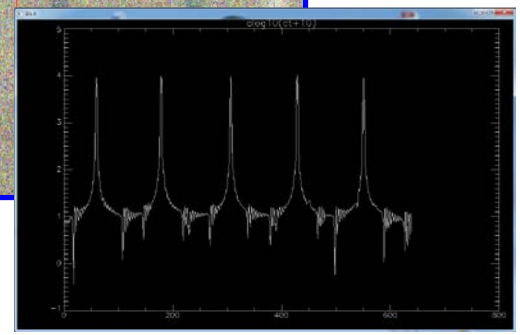


Sensor Artifacts

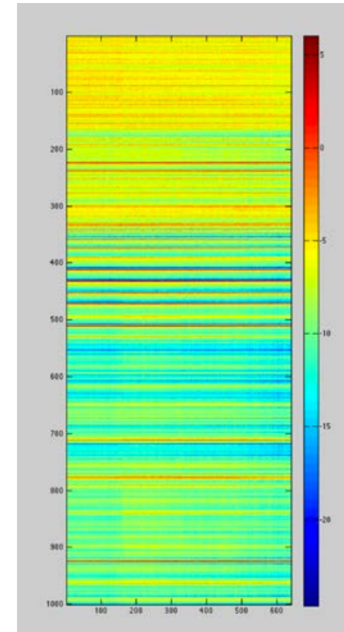
Electronic Panel Ghosting



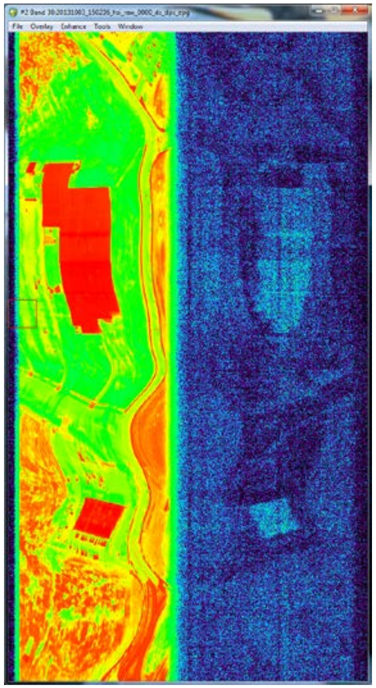
Ringing



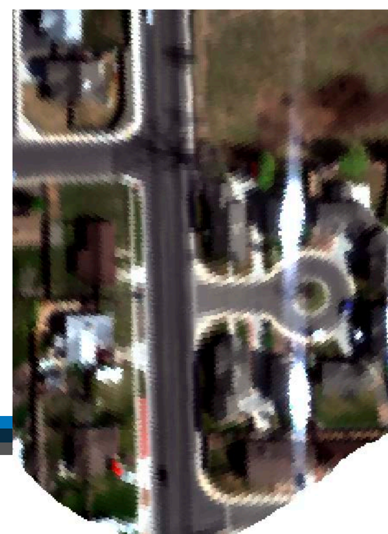
Dark Pedestal Shift



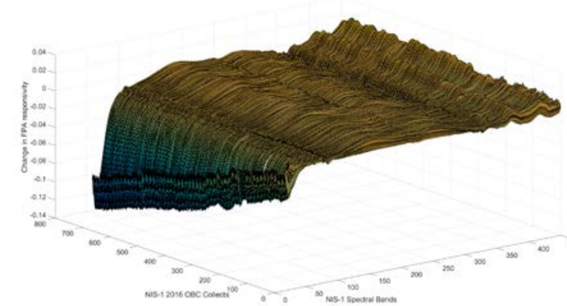
Spectral/Spatial Ghosting



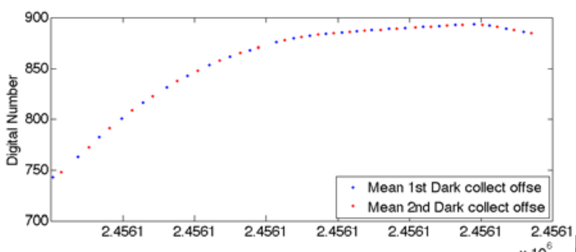
Scattered Light



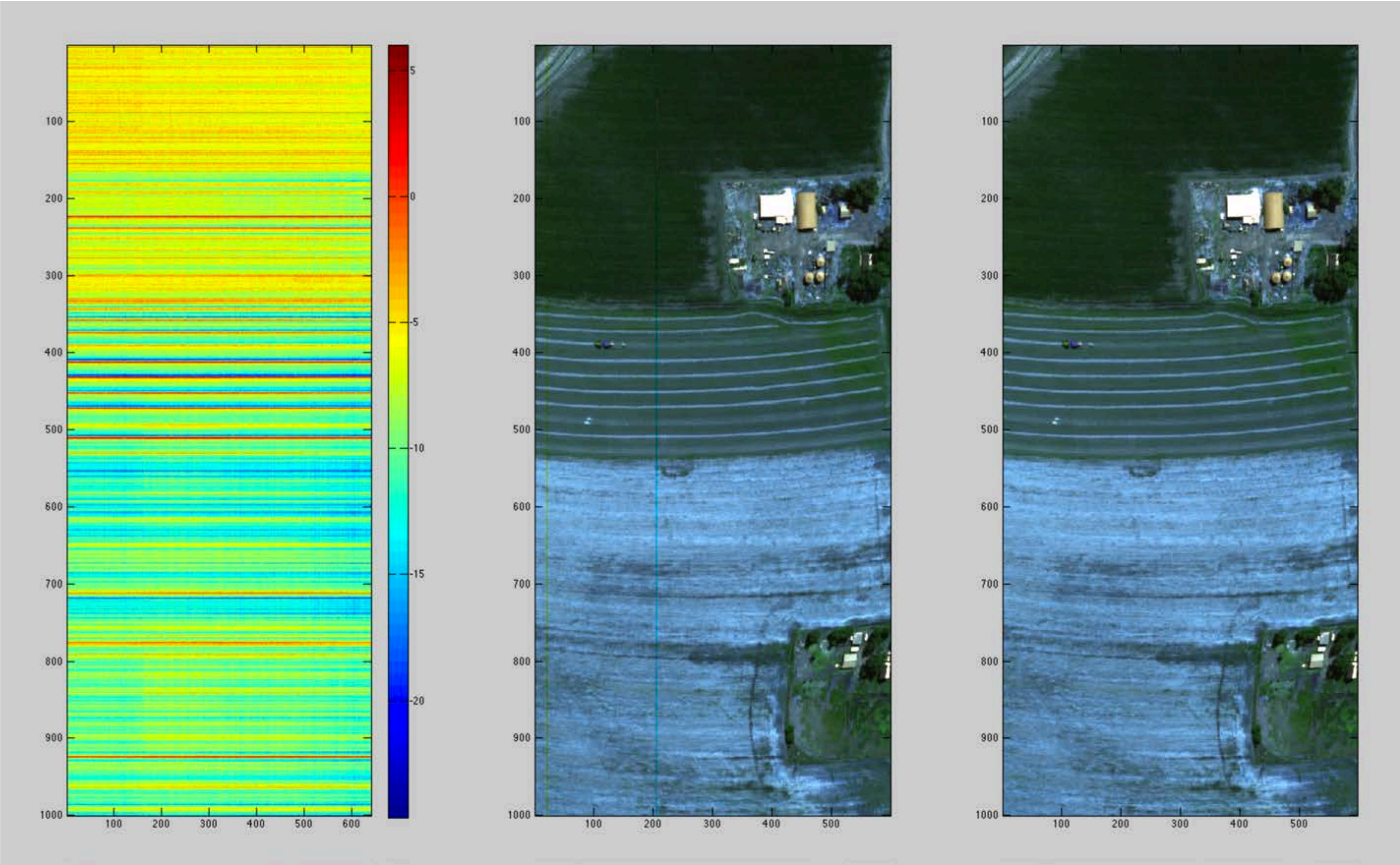
Blue Quantum Efficiency



Variable Dark Offset



Sensor Artifacts: Dark Pedestal Shift



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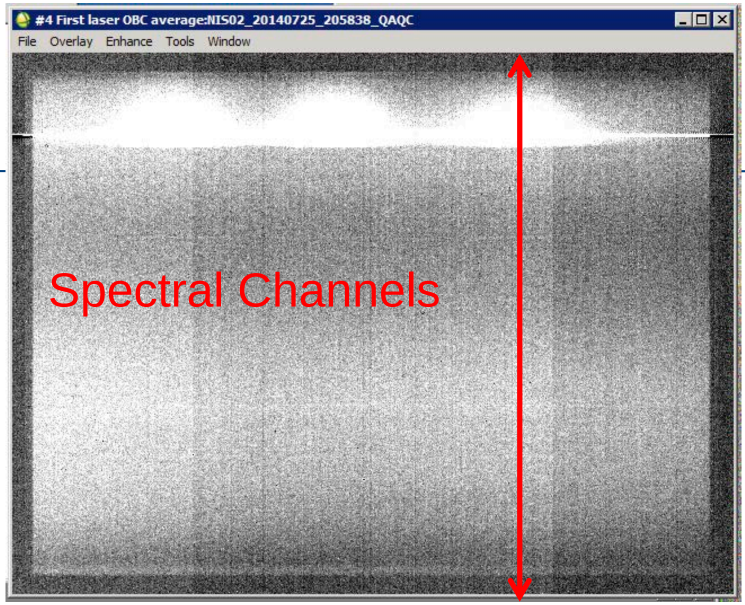
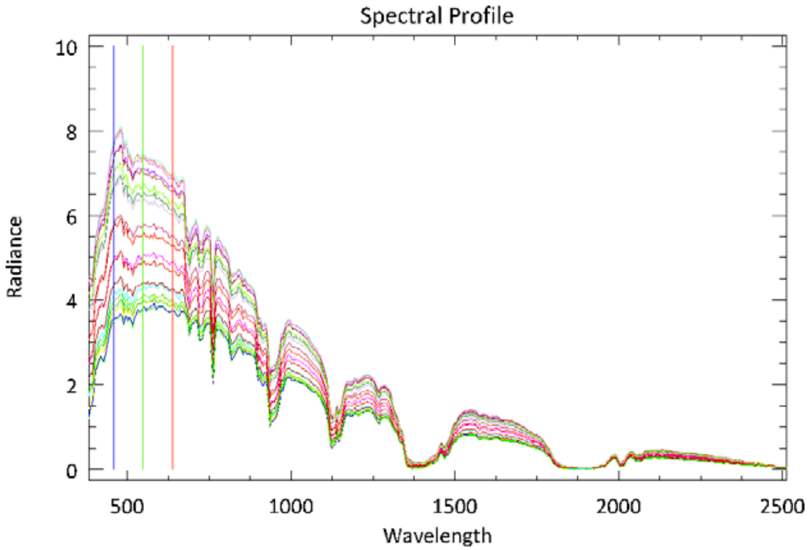
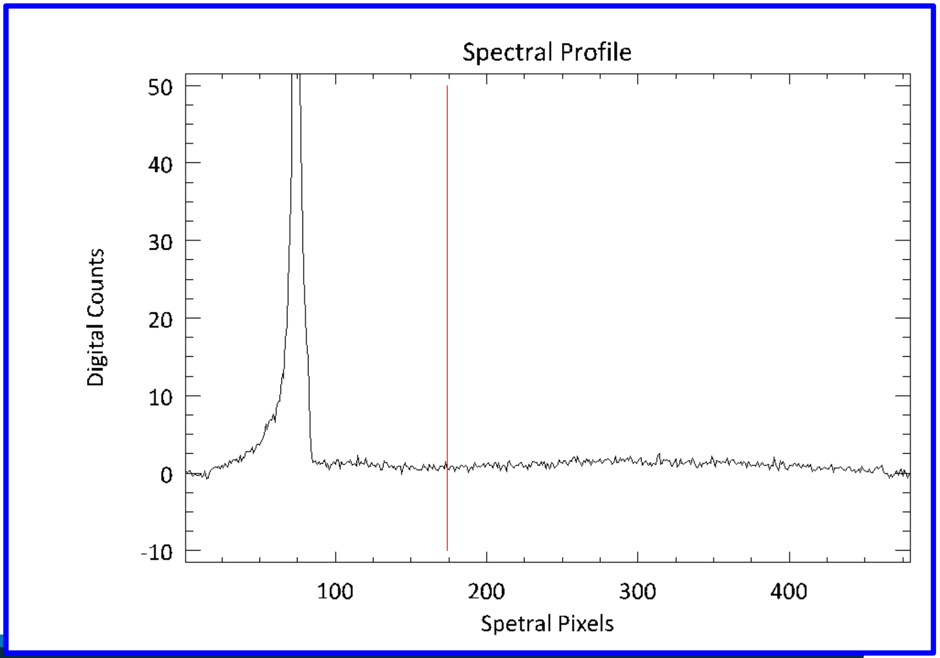
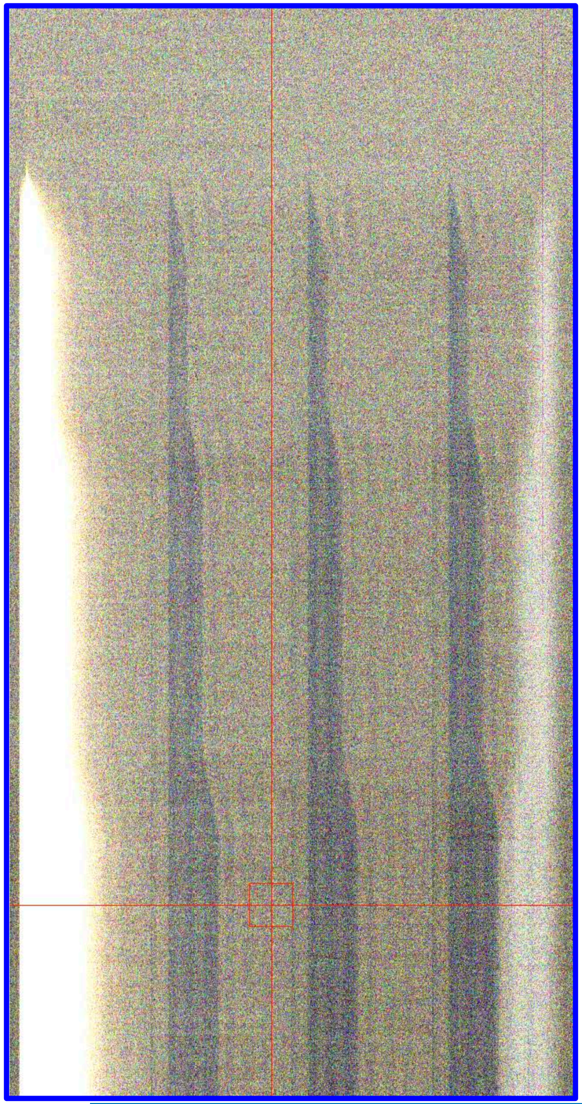
Spatial/Spectral Blur

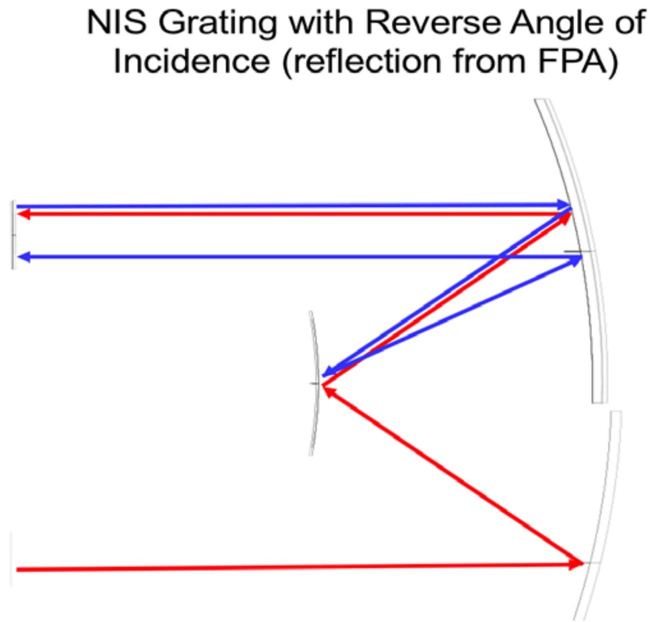


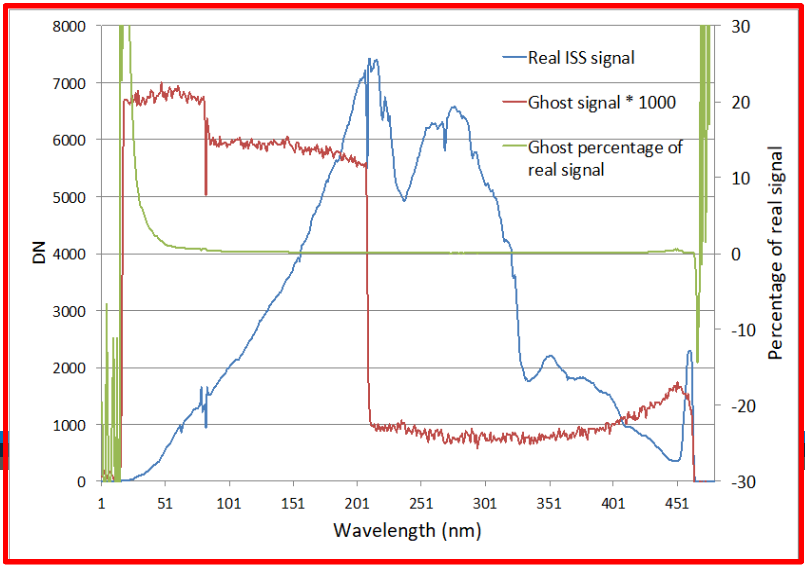


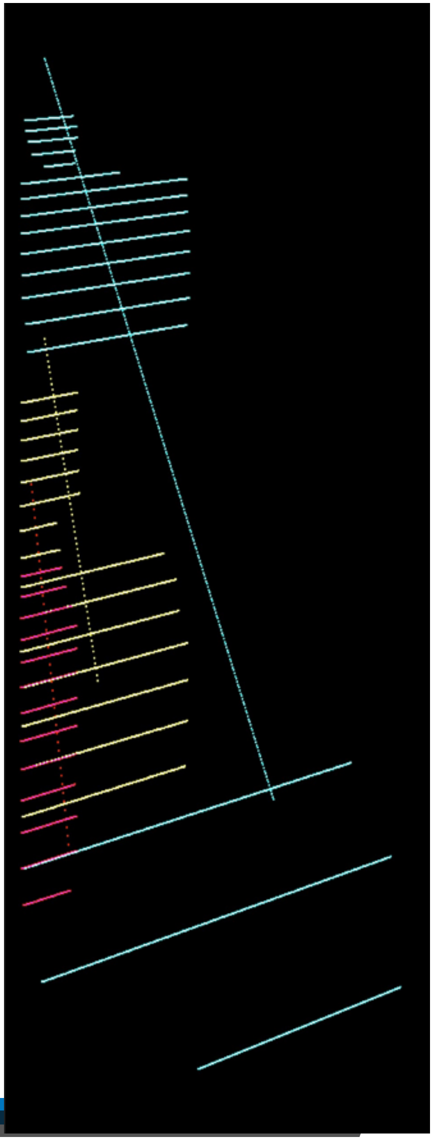


NIS Calibration Data Ghosting









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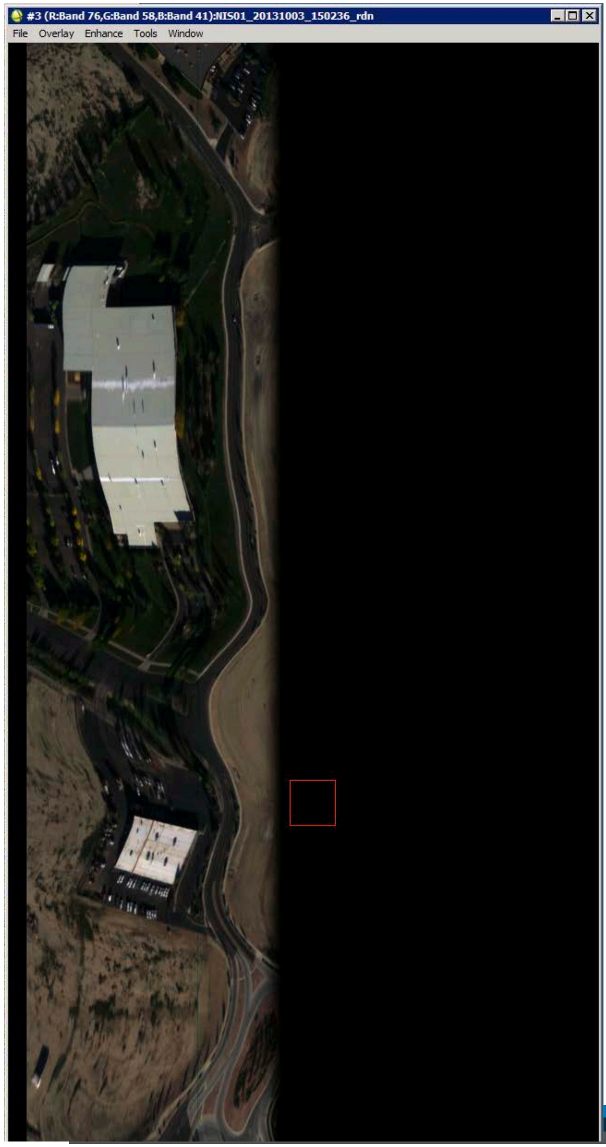
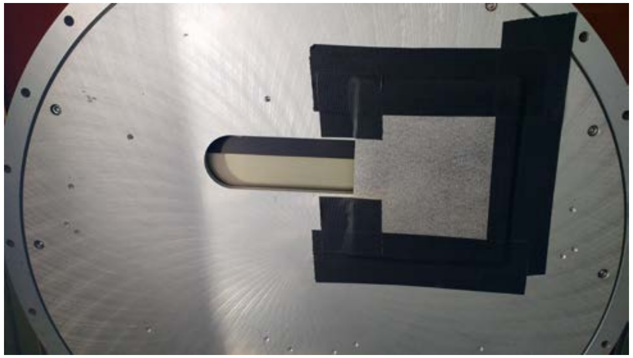
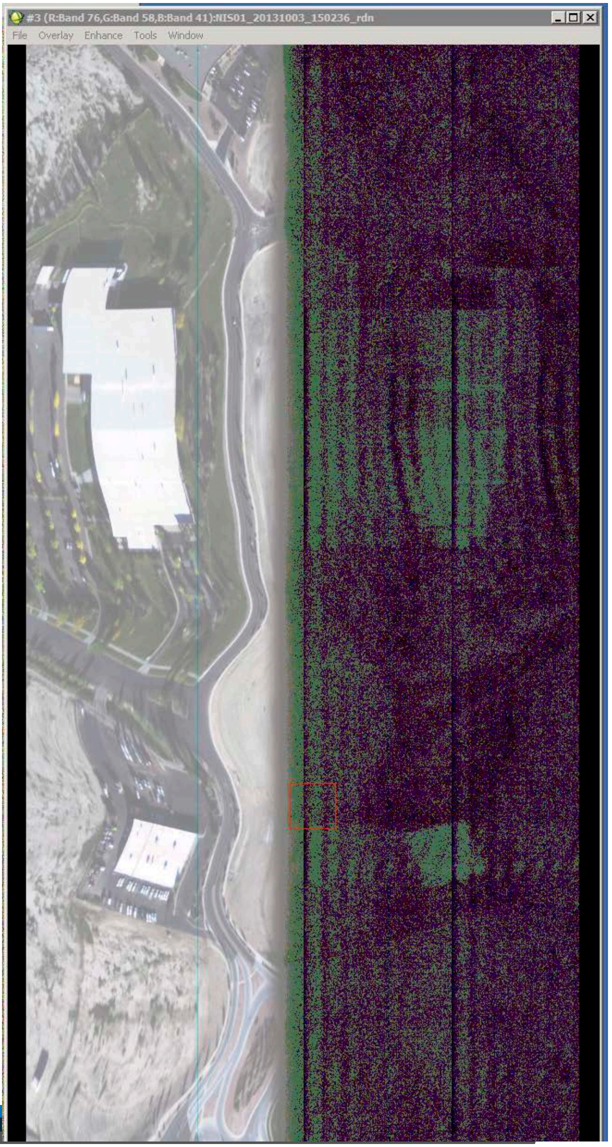
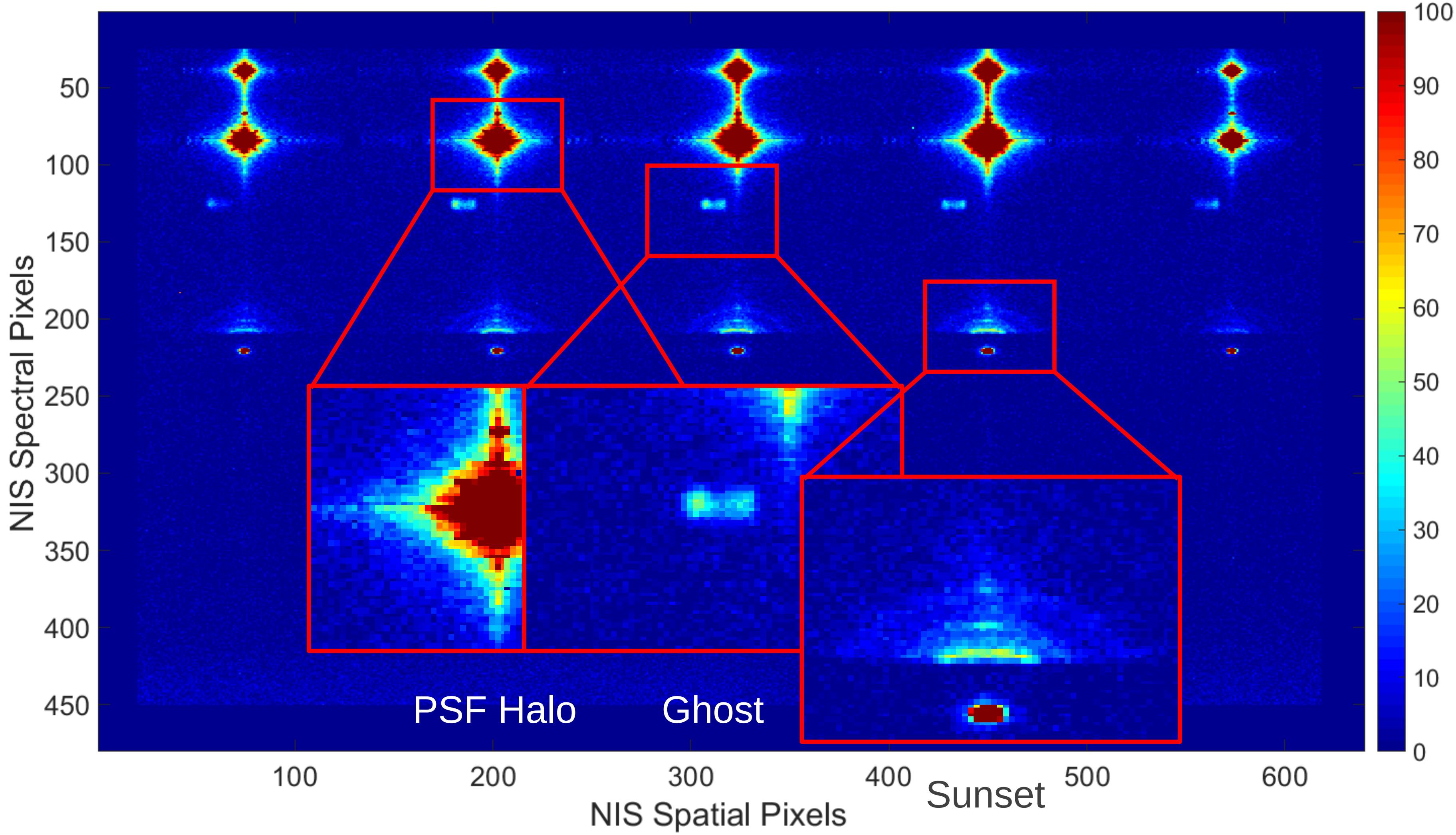
Ghosting in NIS Imagery





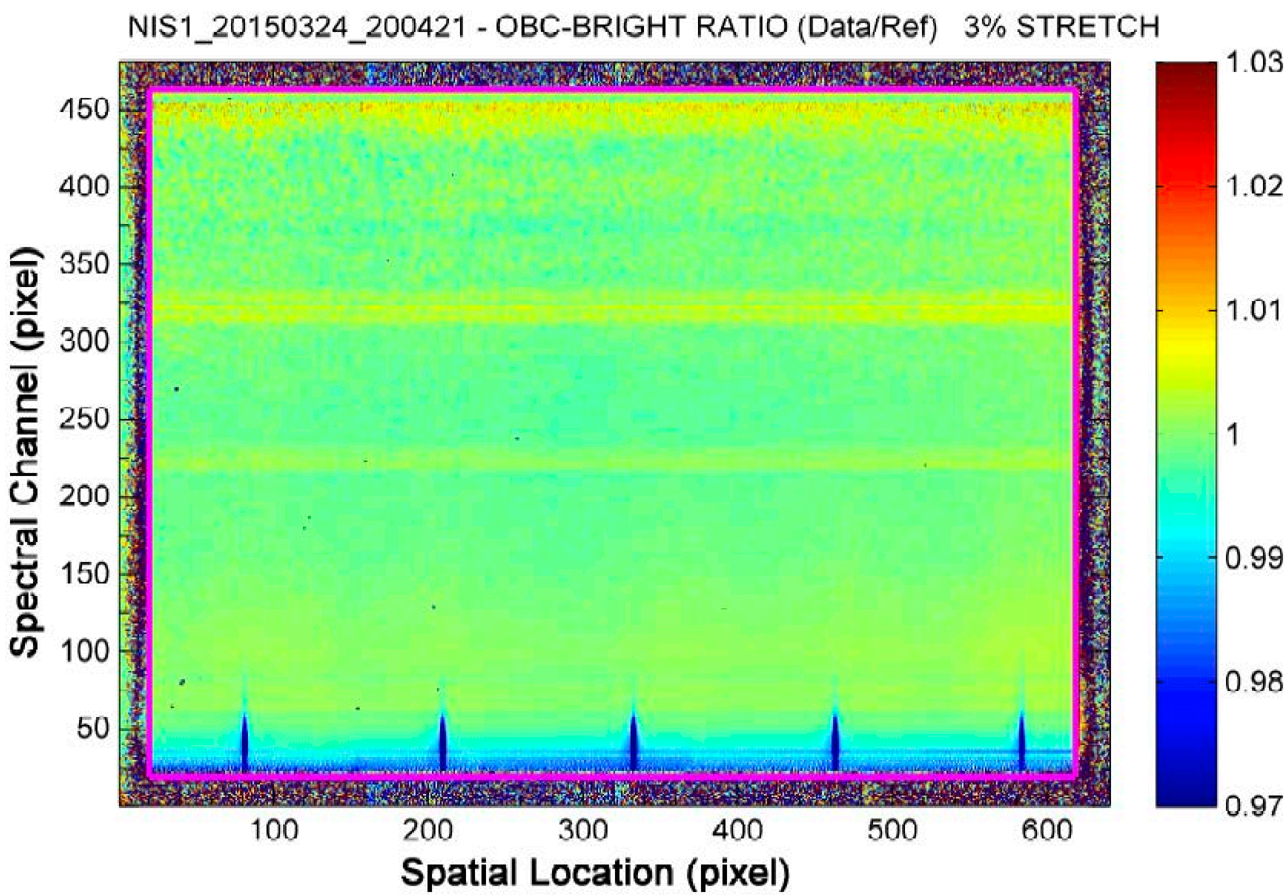


Sample NIS Frame from NEON Lab

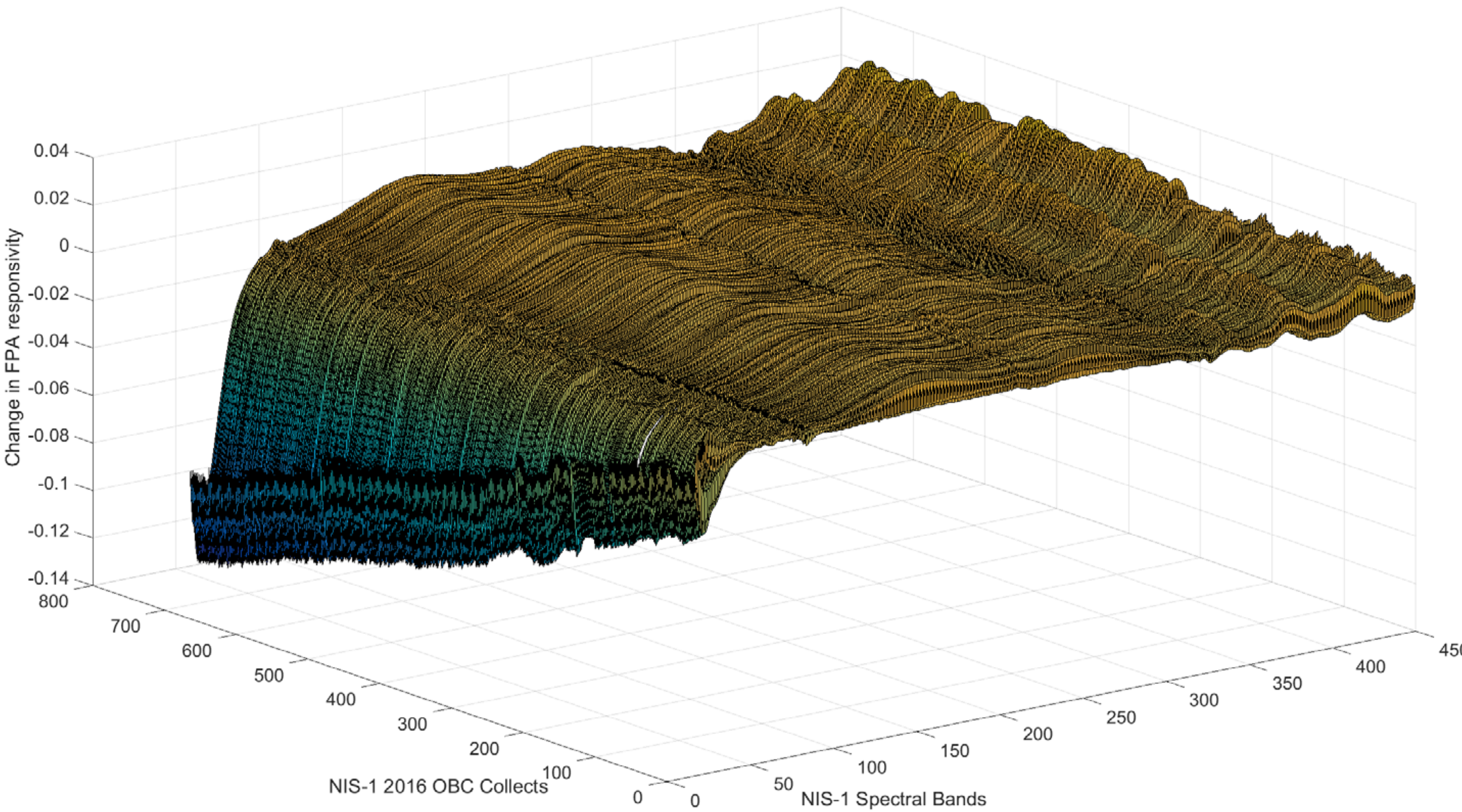


Detector Responsivity Changes

- Discovered during early implementation of the NIS L0 QA algorithm
- Trending using OBC broadband illumination between initial lab collect and science collects
- Responsivity degradation with photon exposure
- Reversed/reset through system warm-up



Blue Quantum Efficiency Shift



Improvements in the NIS Sensor Model

Offset Corrections

- Dark Offset Subtraction
- Dark Pedestal Shift
- *Electronic Panel Ghost*
- **Spatial/Spectral Ghosting**
- **Spatial/Spectral Blur**
- Ringing
- OSF Sunset

Gain Application

- **Blue Quantum Efficiency**
- Linearity
- Flat Field Correction
- Radiometric Calibration

System Characterization

- Trim data to used FPA area
- *Bad Detector Element mapping*
- **Bad Detector Element Correction**
- Order Sorting Filter Boundaries
- Spectral 3mapping
- Orthorectification

Improvements in the NIS Sensor Model

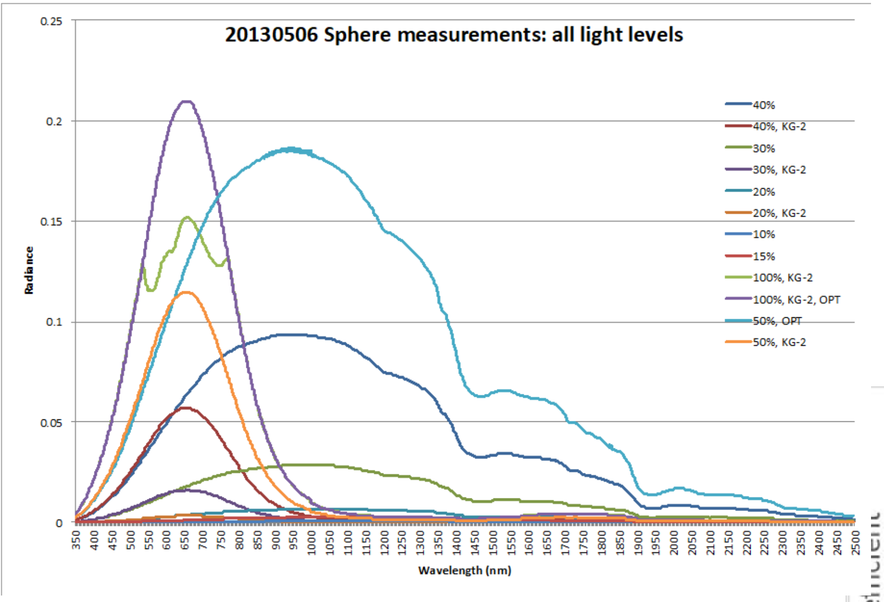
Algorithm Improvements

- Implemented in lab data reduction algorithms used to produce the calibration
- Implemented in the Science Data Record algorithms
- Also implemented in the L0 Quality Checks (not discussed here)

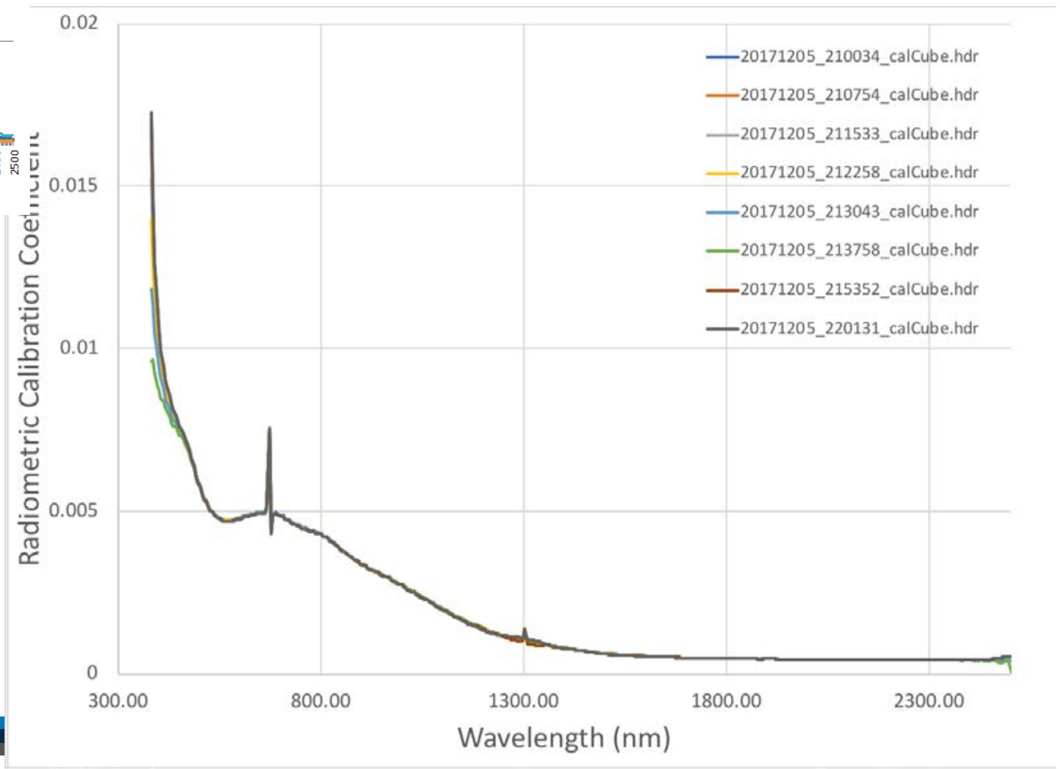
Results

- Improvements in lab calibration results
- Improvements in the Science Data Record accuracy

Lab Calibration Improvements



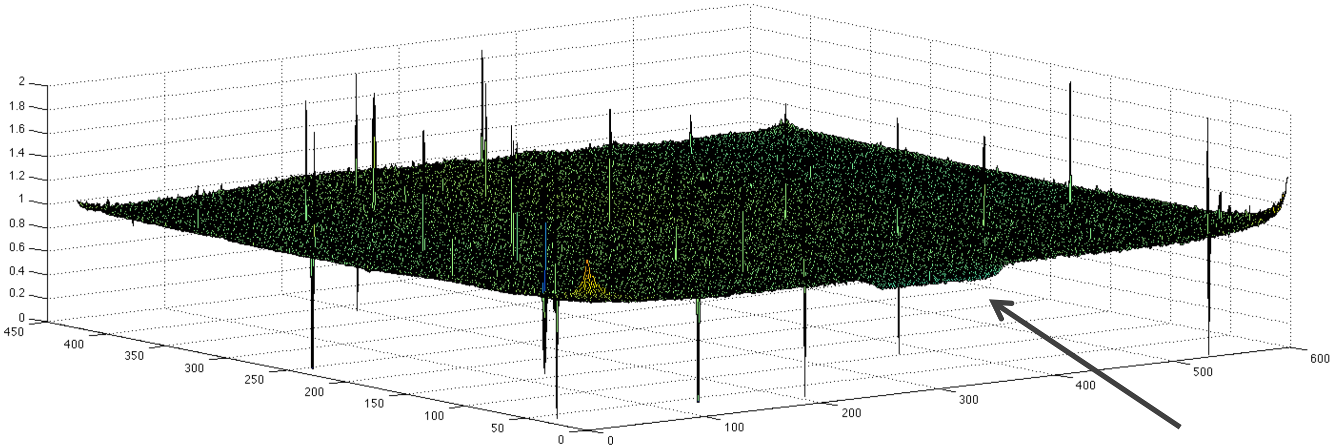
Variability in calibration reduced



If the understanding of the radiometric sensor model is accurate, the calibration should not change under varied calibration illumination levels

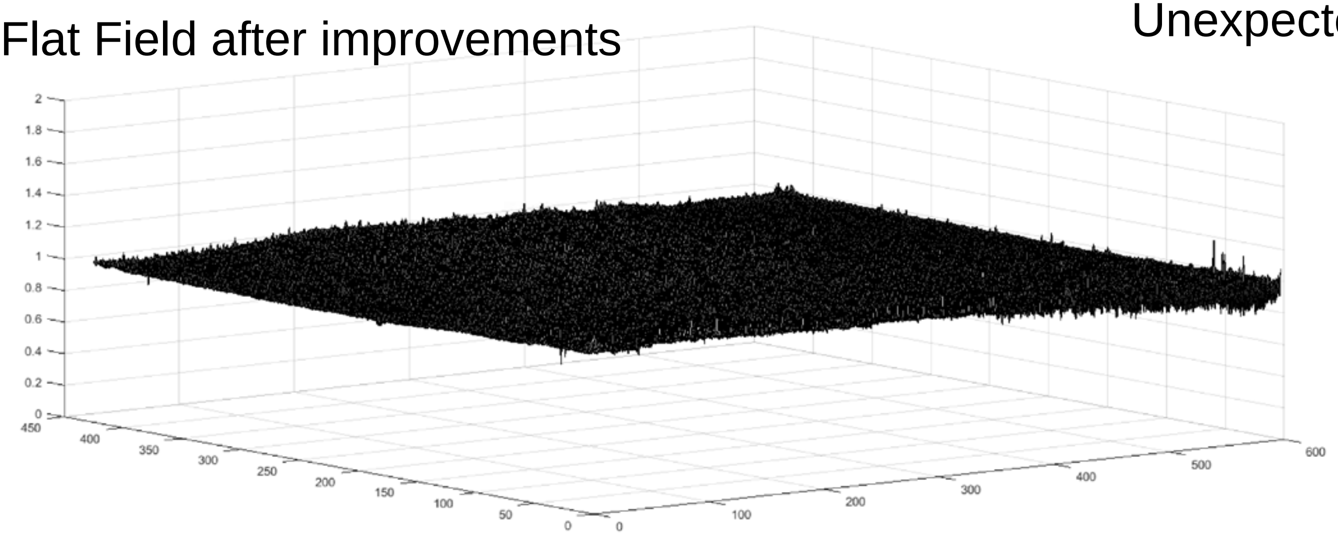
NIS Calibration Data Ghosting

Flat Field with Ghosting artifact

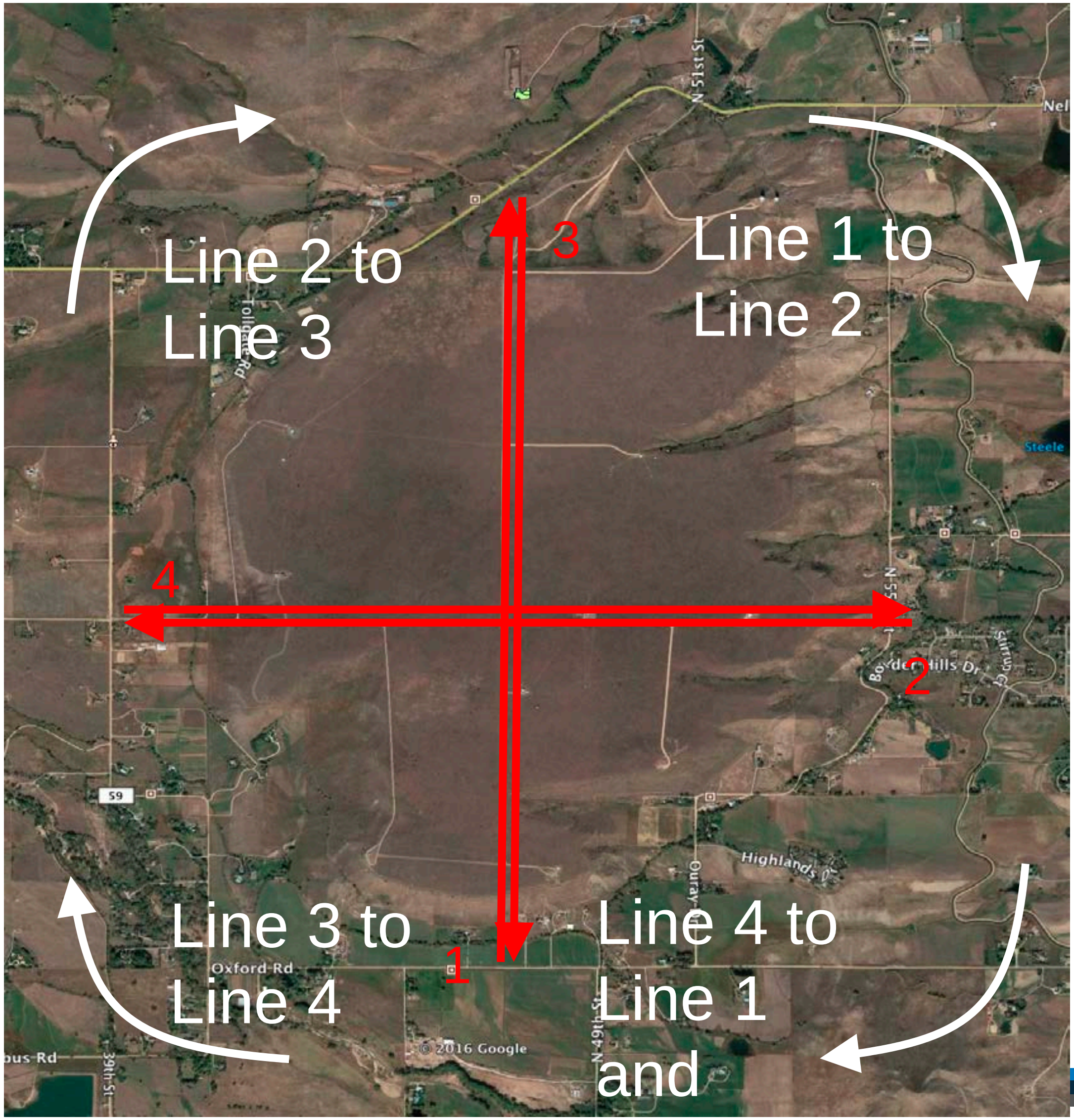


Unexpected artifact

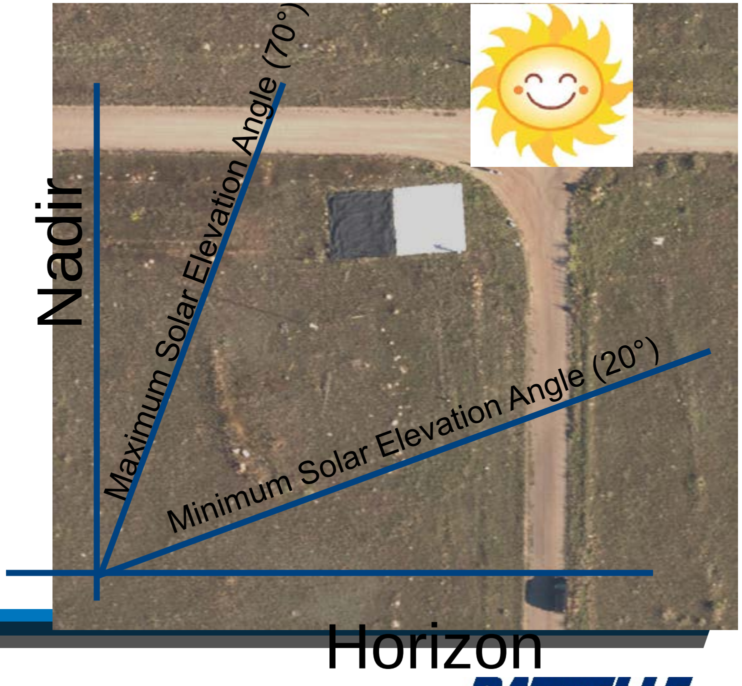
Flat Field after improvements



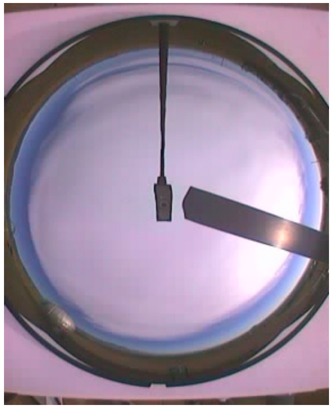
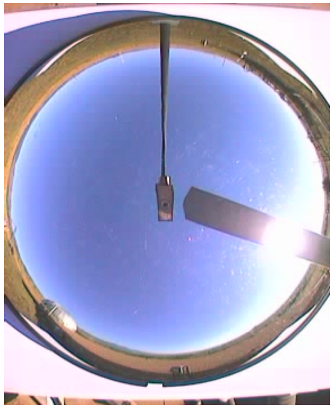
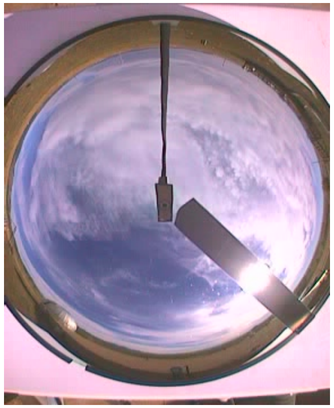
NIS Vicarious Calibration



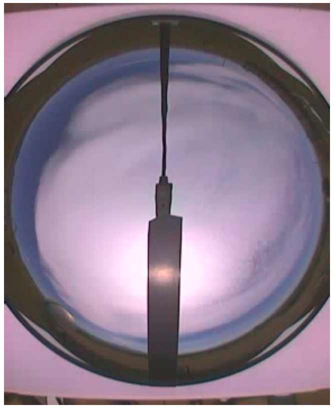
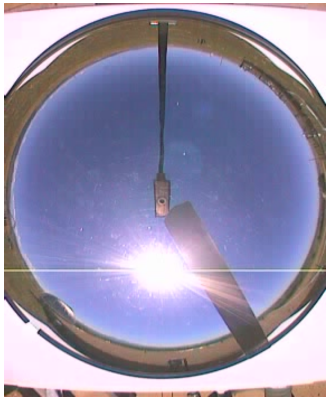
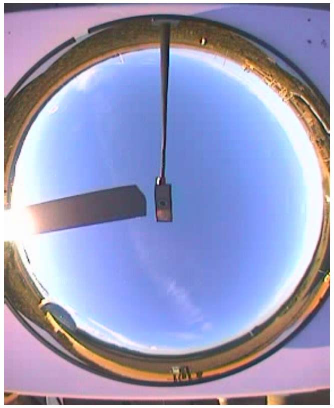
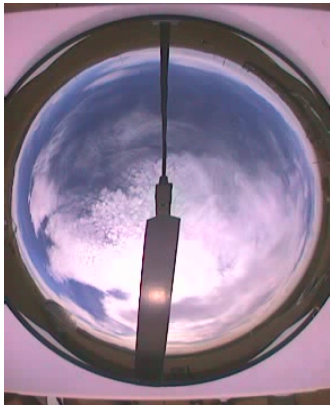
- Radiometric Calibration flight typically conducted pre- and post- flight season
- Extended collects under varying weather conditions across range of solar illumination angles



Weather Conditions

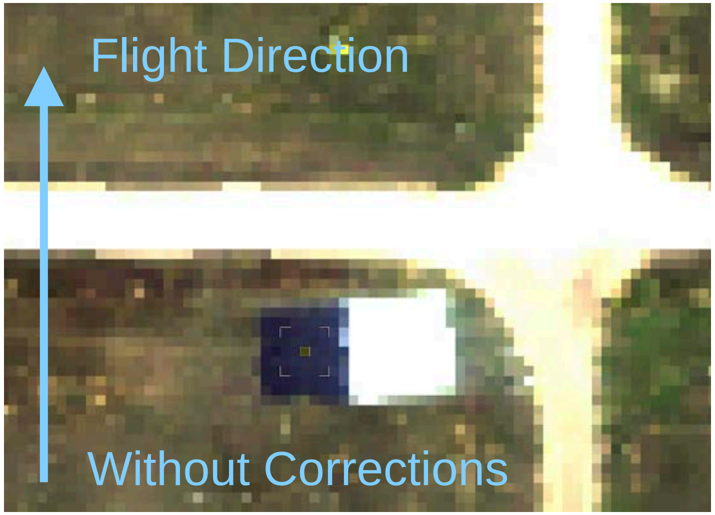
Day 1	Day 2	Day 3	Day 4
			

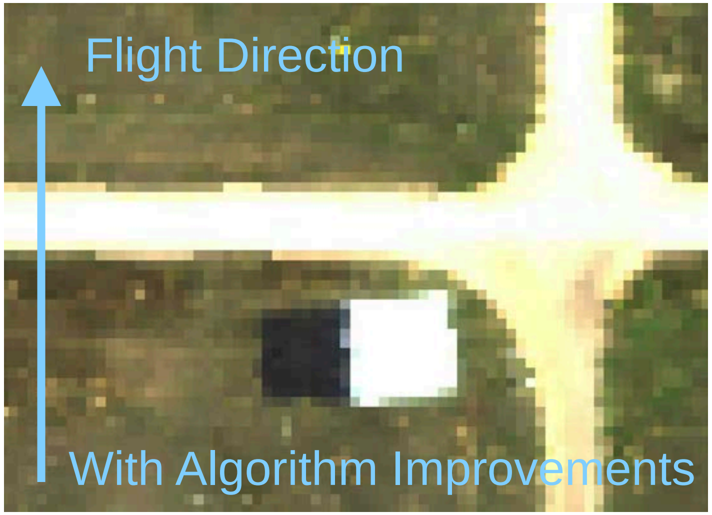
Sky conditions at the start of NEON’s airborne collect

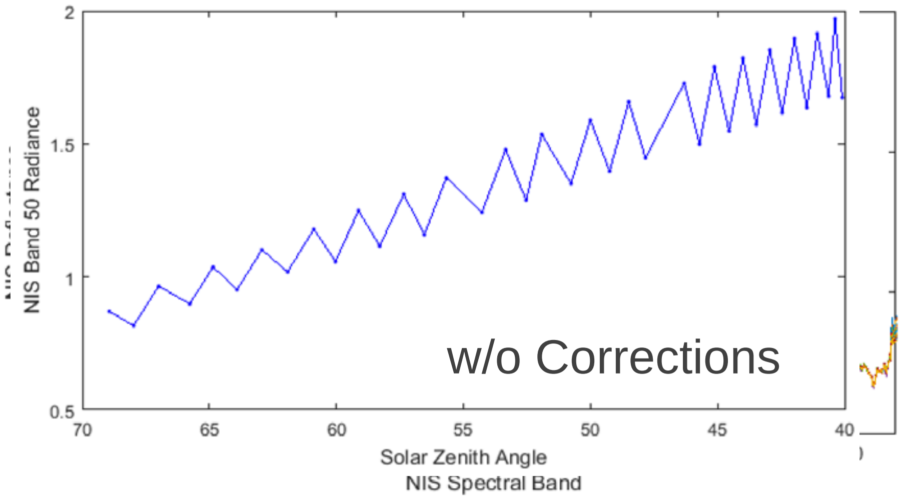
			

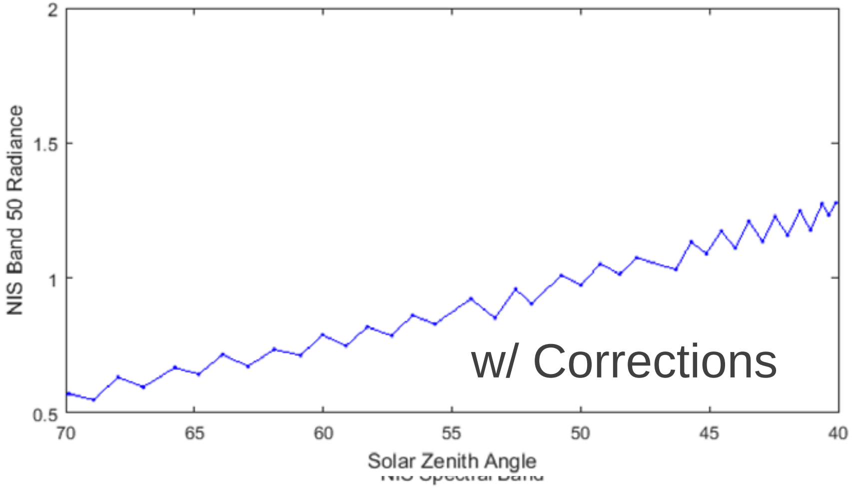
Sky conditions at the completion of NEON’s airborne collect

Initial Results and Calibration Improvements

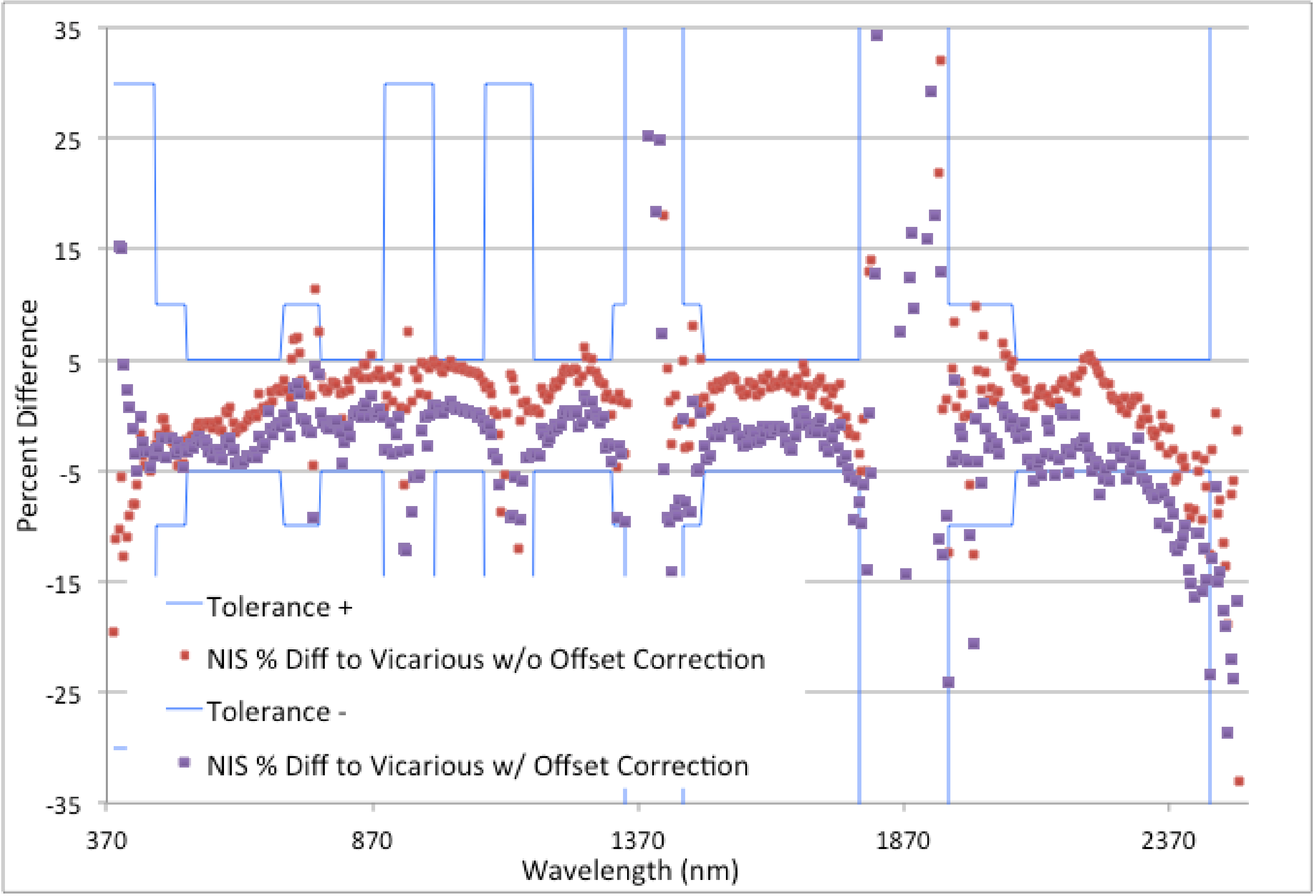




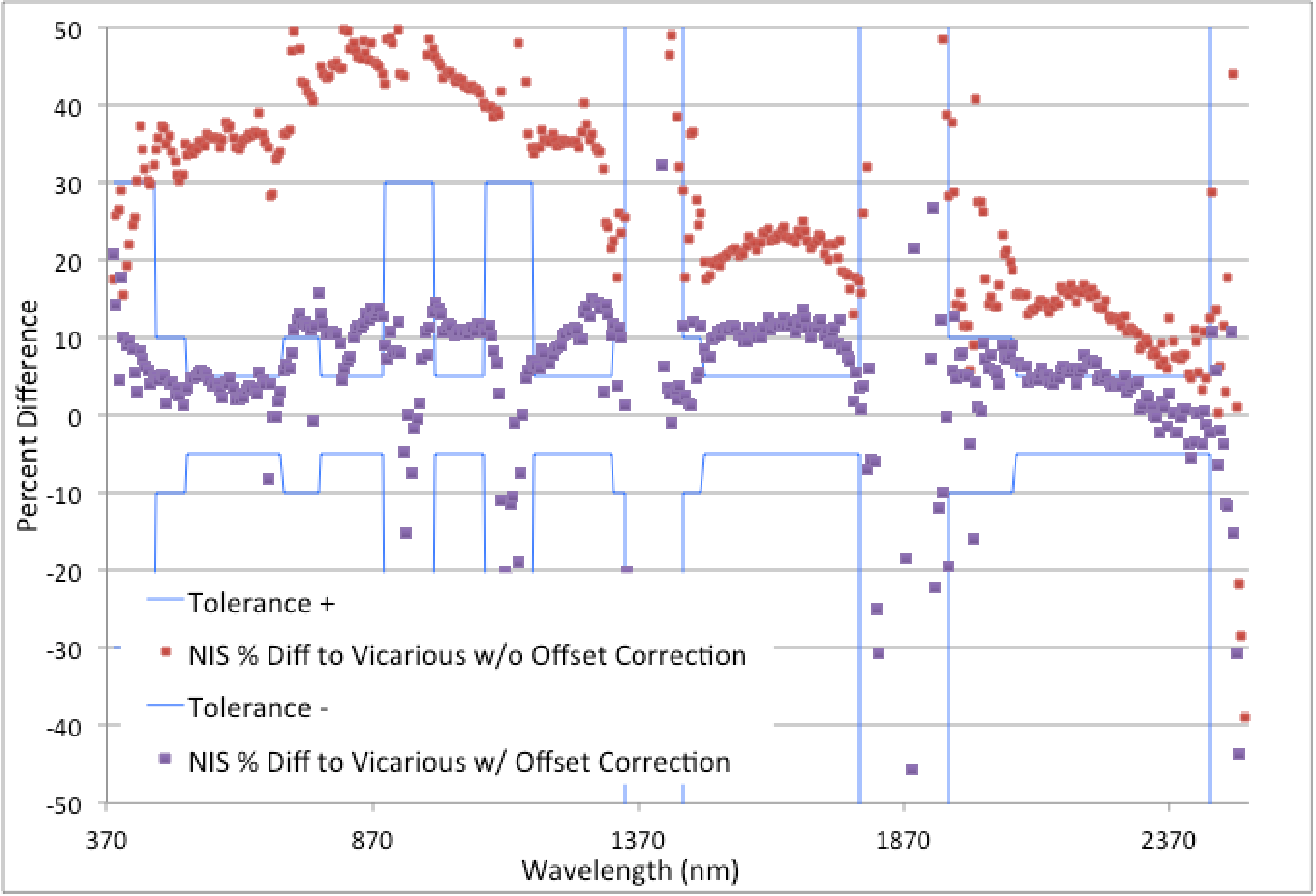




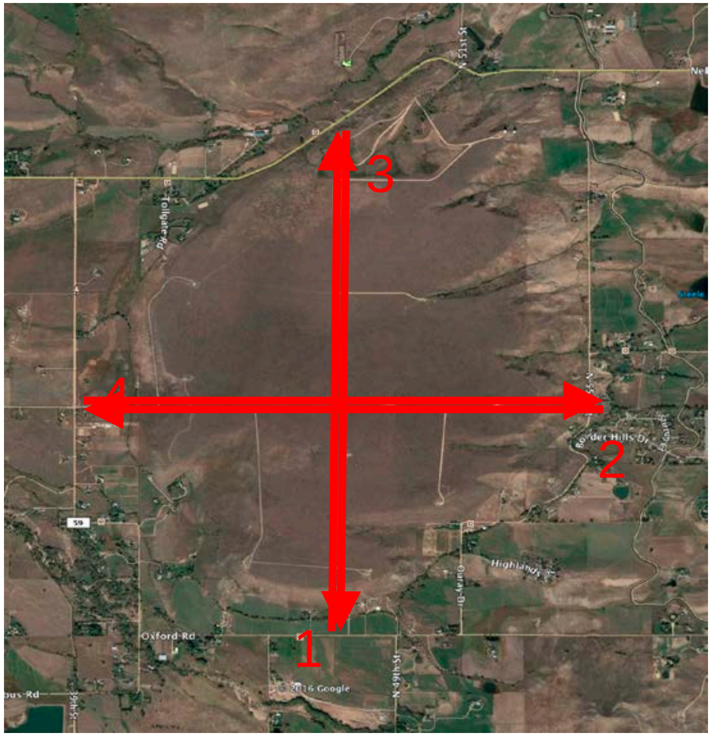
Improved Sensor Calibration Corrections

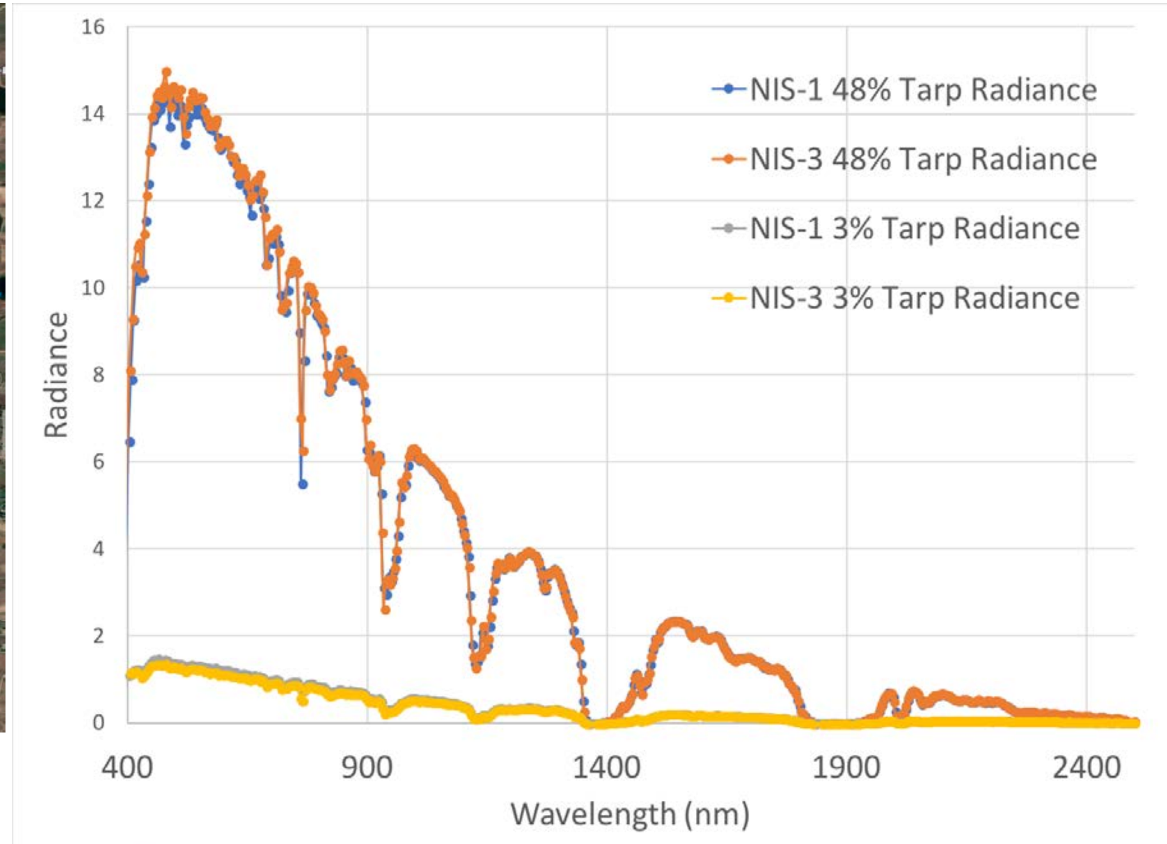


Improved Sensor Calibration Corrections



NIS Inter-comparison





Payload-1 flown back-to-back with Payload-3 over vicarious calibration site at TBMT

Conclusions

- Gain and offset are intimately linked
- Vital to accurately understand the sensor
- Without corrections, true offset never obtained
- Lead to errors in the calibration (Lab or Vicarious)
- Also leads to errors in at-sensor radiance and higher-lever products
- While we have implemented various calibration improvements, there remains work that can be done.
- The key is to determine when the calibration meets requirements

THANKS!

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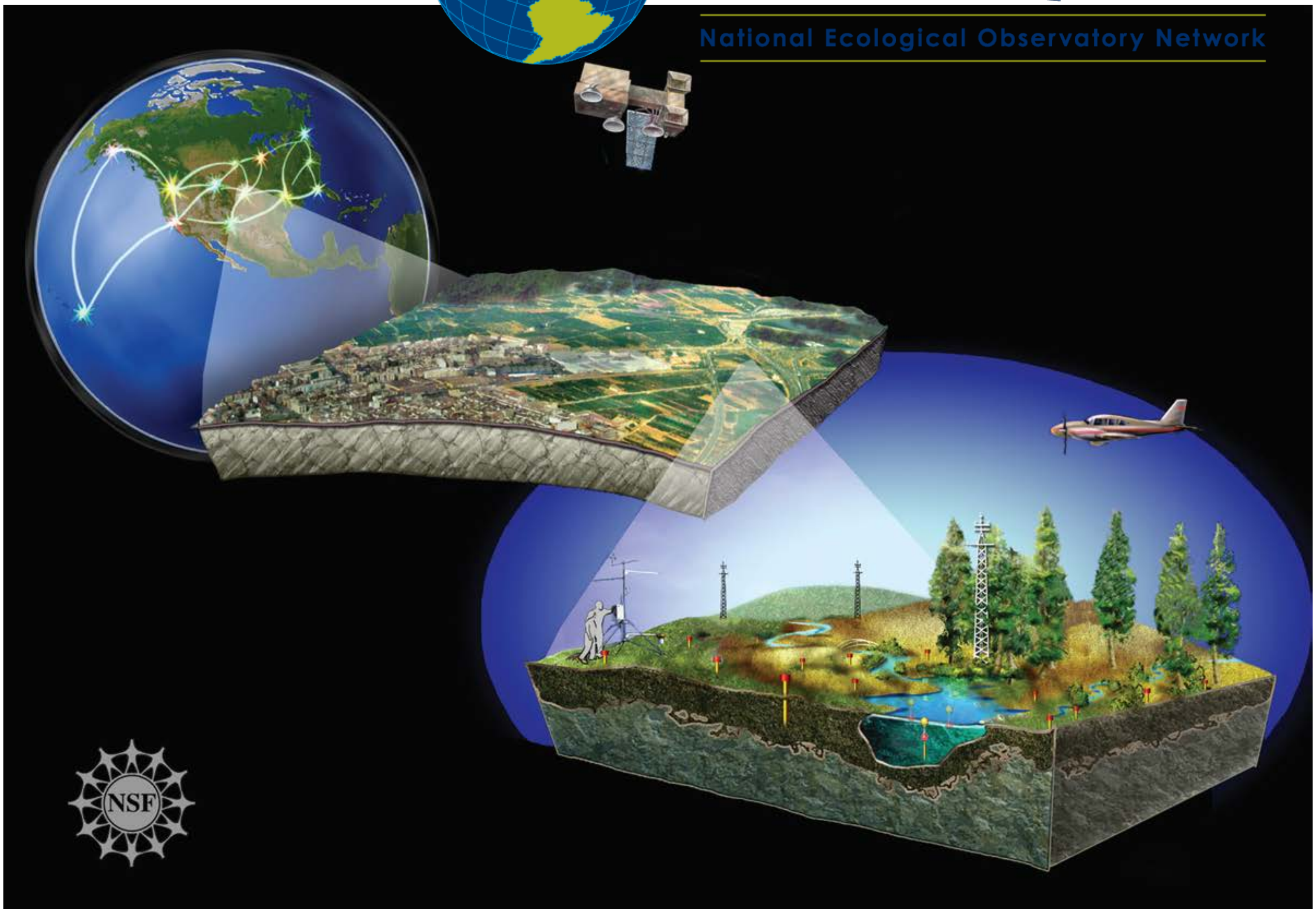
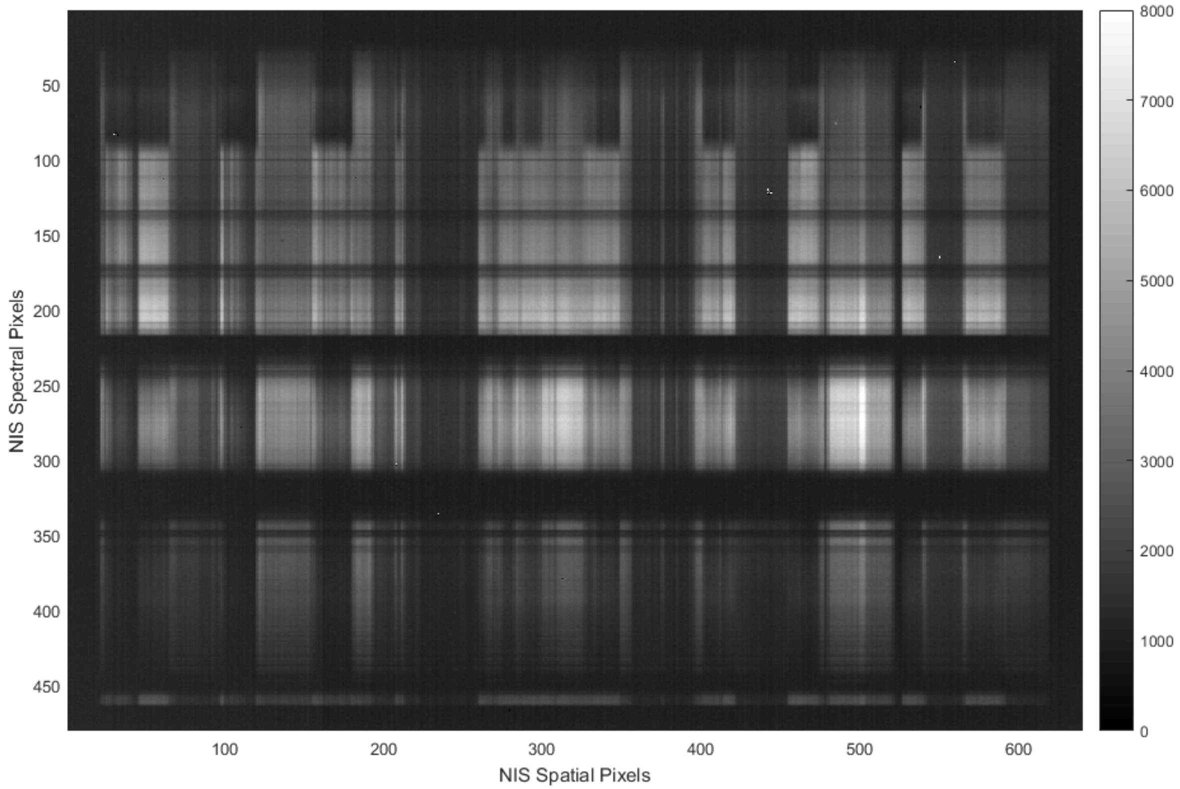
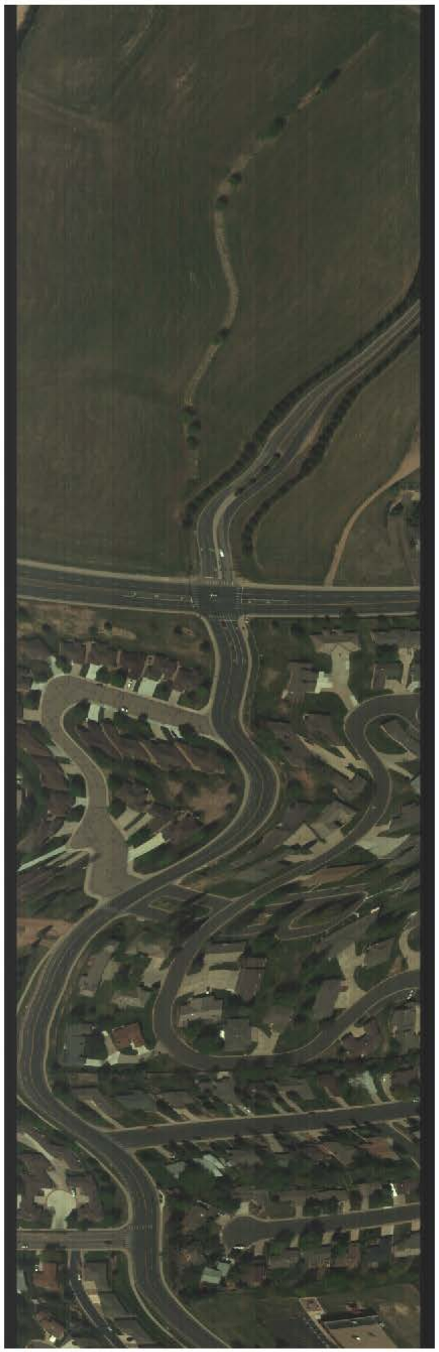


NIS Level-1 Calibration Data Pro

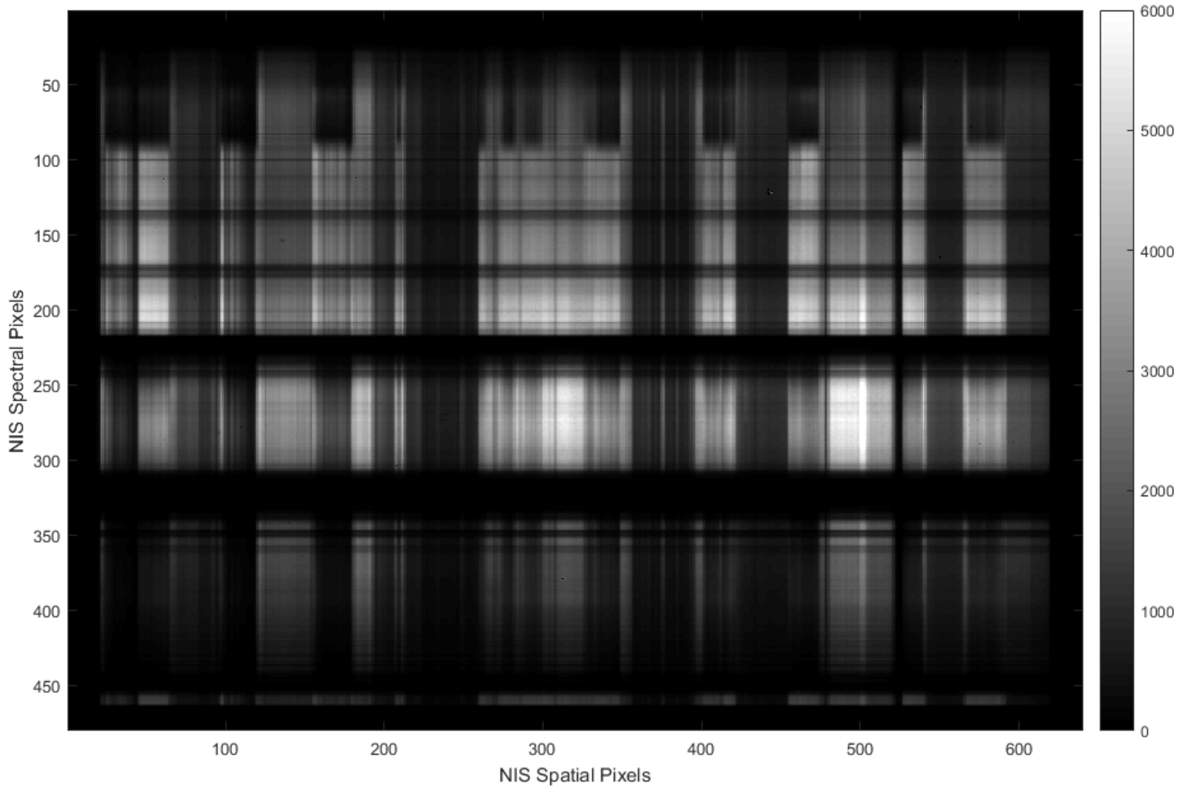


Raw



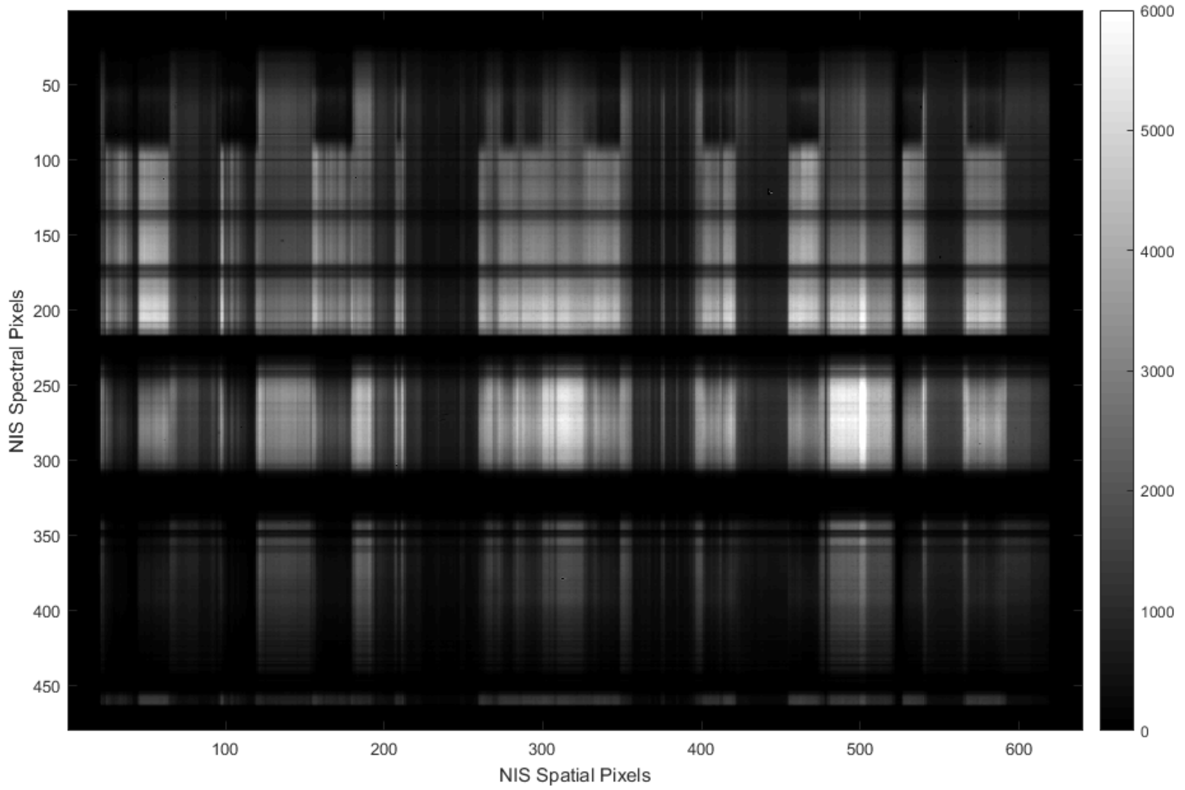
NIS Spatial Pixels

NIS Level-1 Calibration Data Pro



Raw-DS

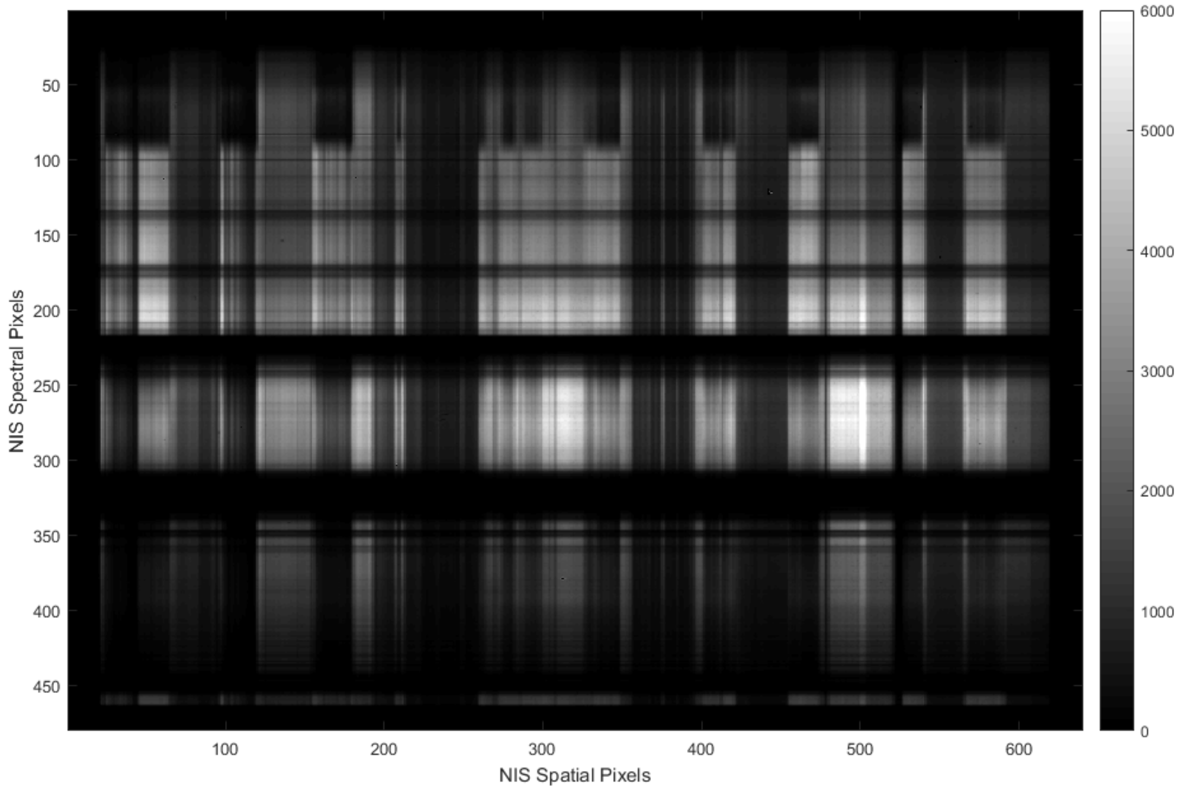
NIS Level-1 Calibration Data Pro



NIS Spatial Pixels

Raw-DS-DPS

NIS Level-1 Calibration Data Pro



Raw-DS-DPS-EPG

NIS Spatial Pixels

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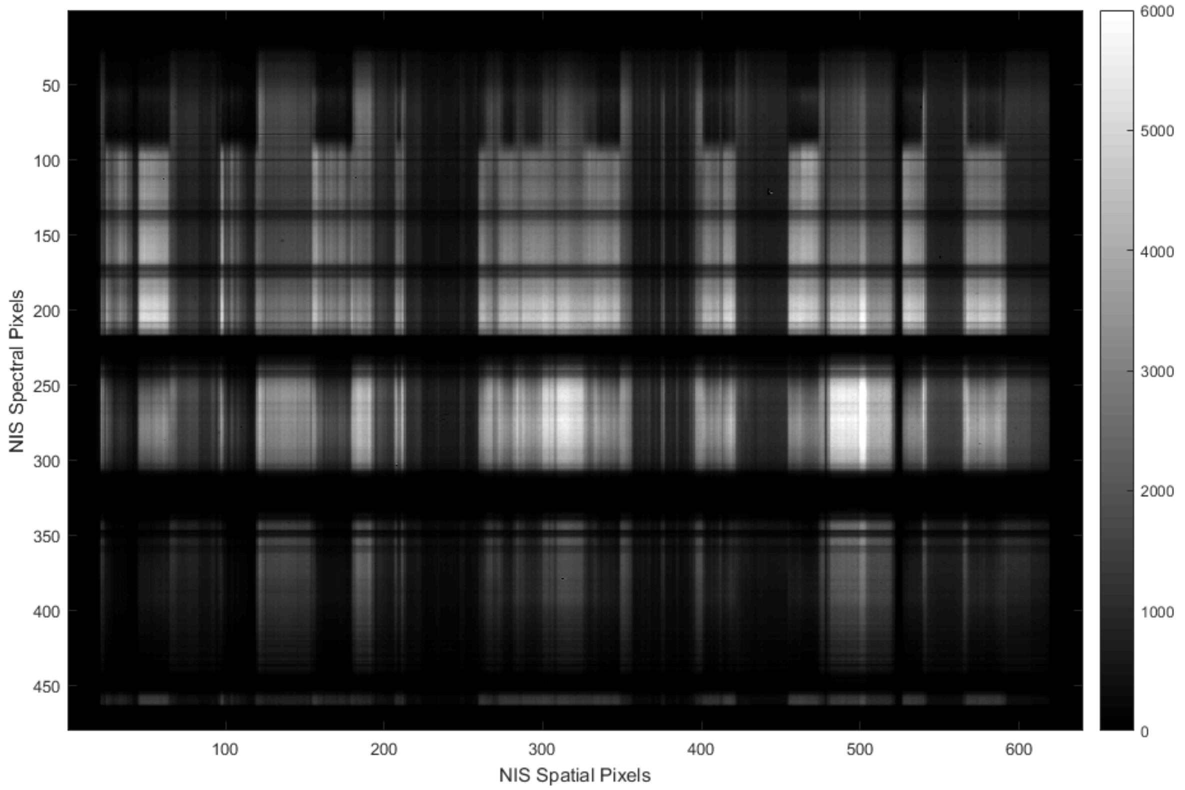
NIS Level-1 Calibration Data Pro



Raw-DS-DPS-EPG-GC

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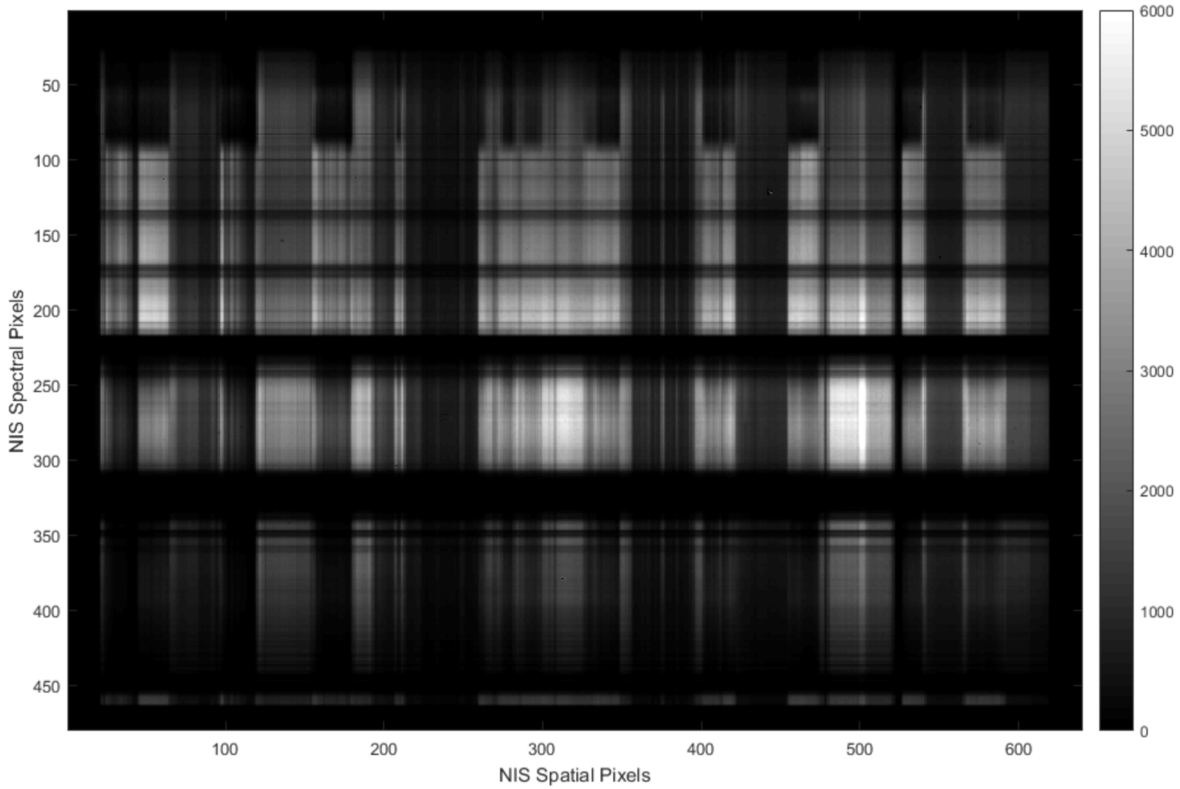

Raw-DS-DPS-EPG-GC-BC

NIS Spatial Pixels

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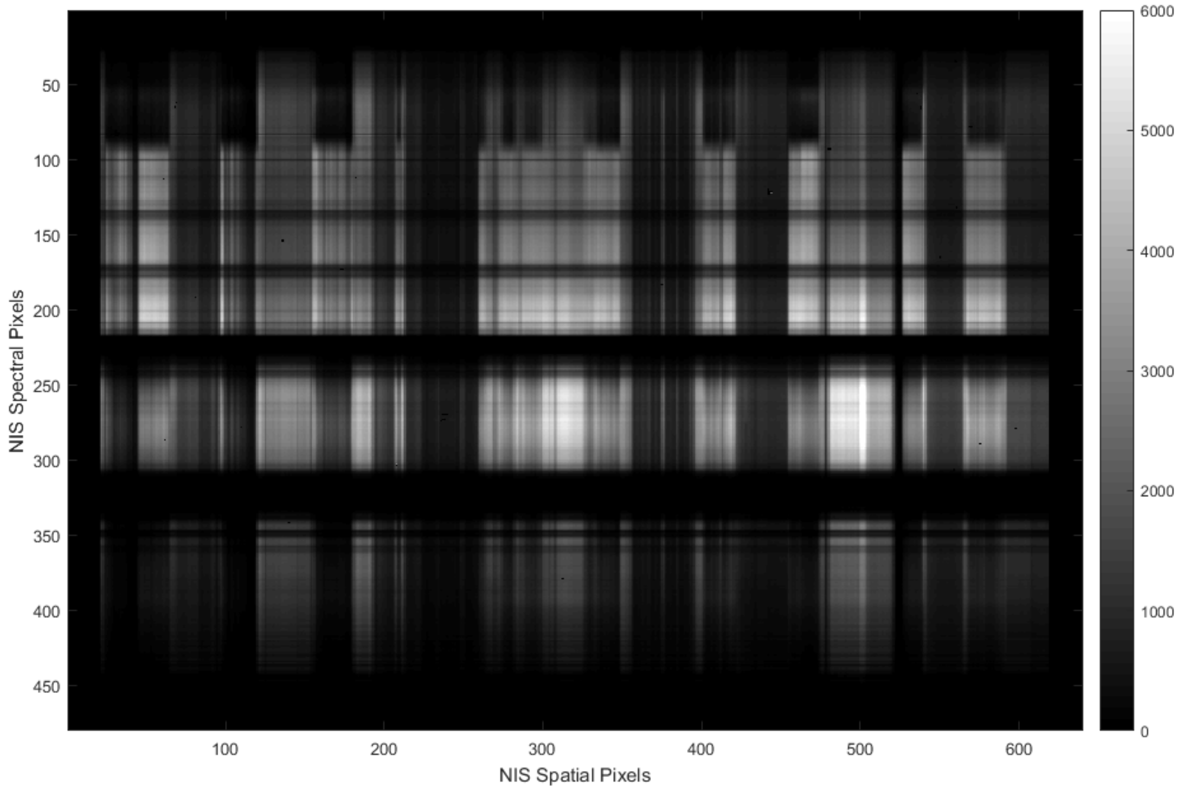
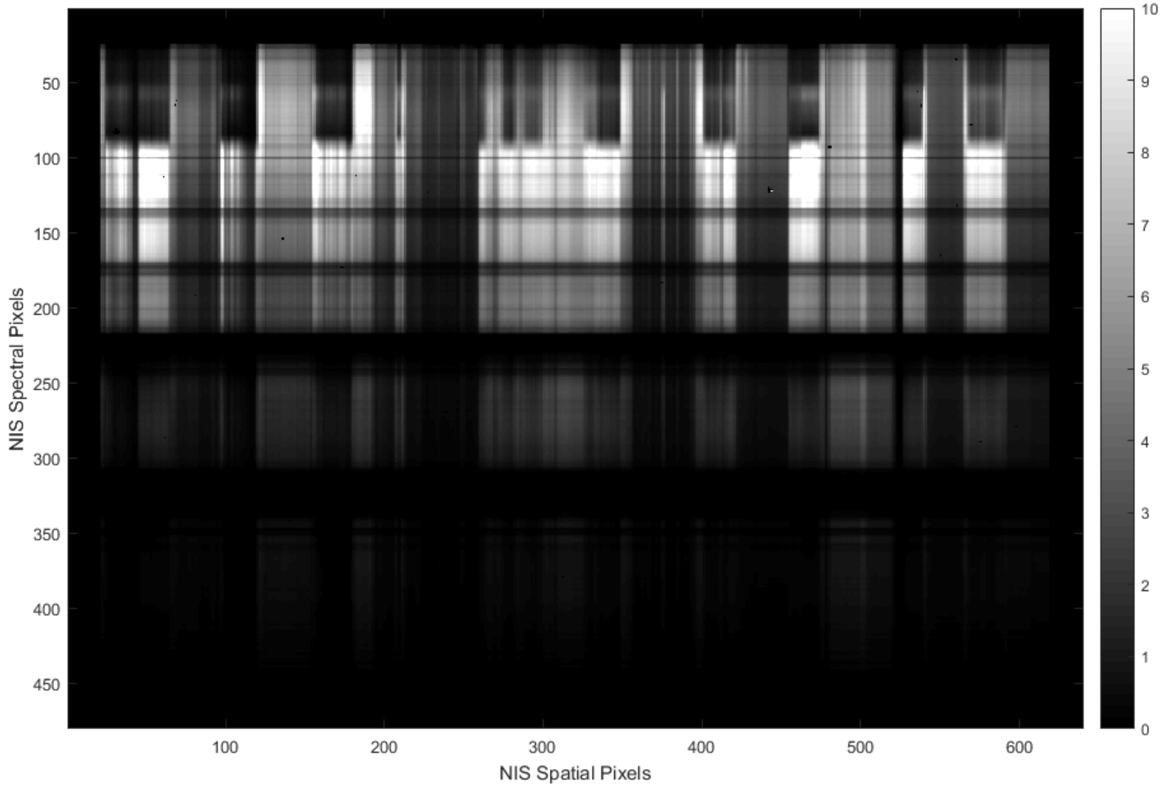
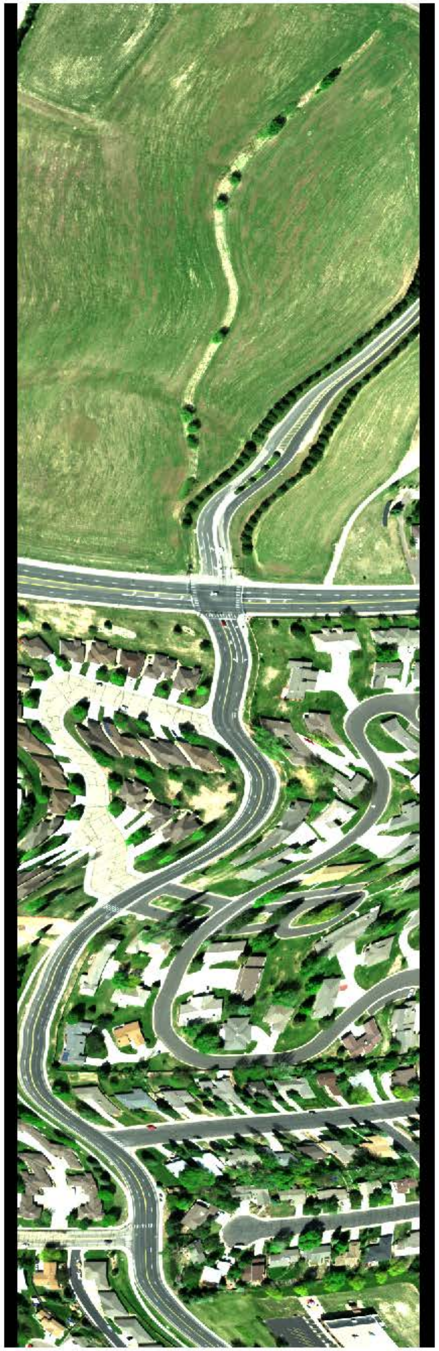
NIS Level-1 Calibration Data Pro



(Raw-DS-DPS-EPG-GC-BC)*FF

NIS Level-1 Calibration Data Pro

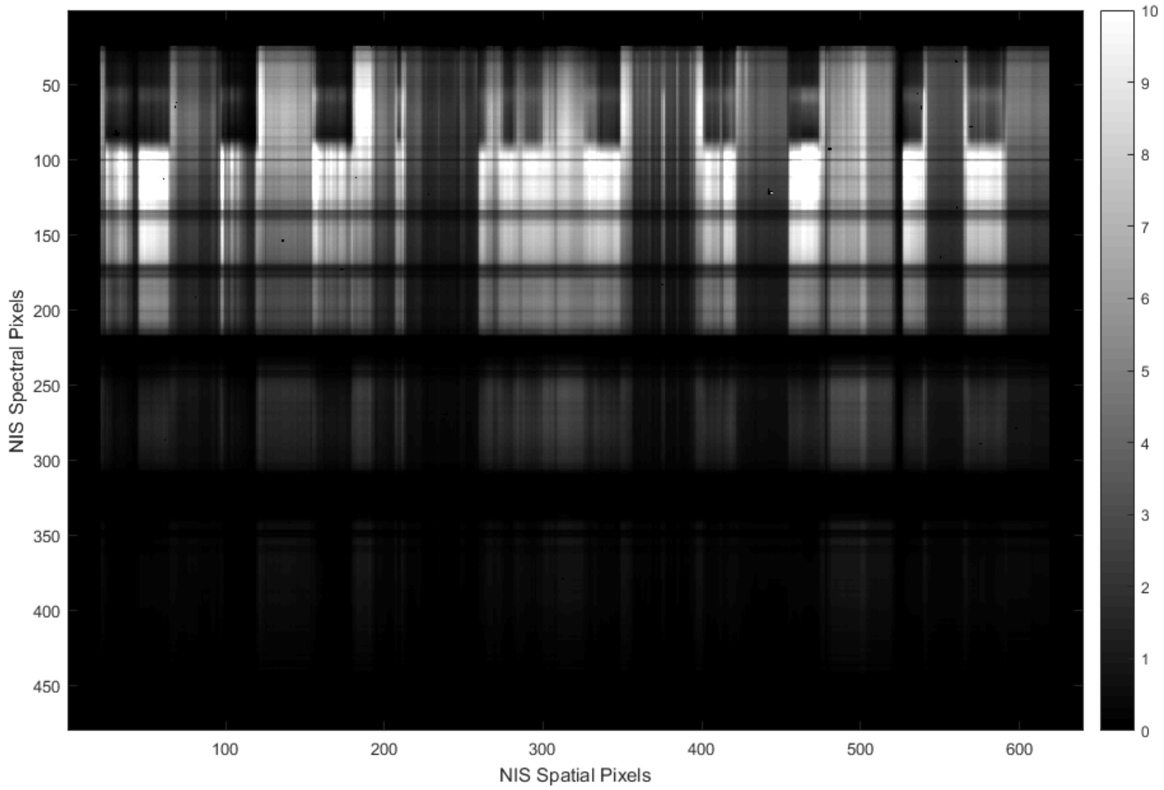


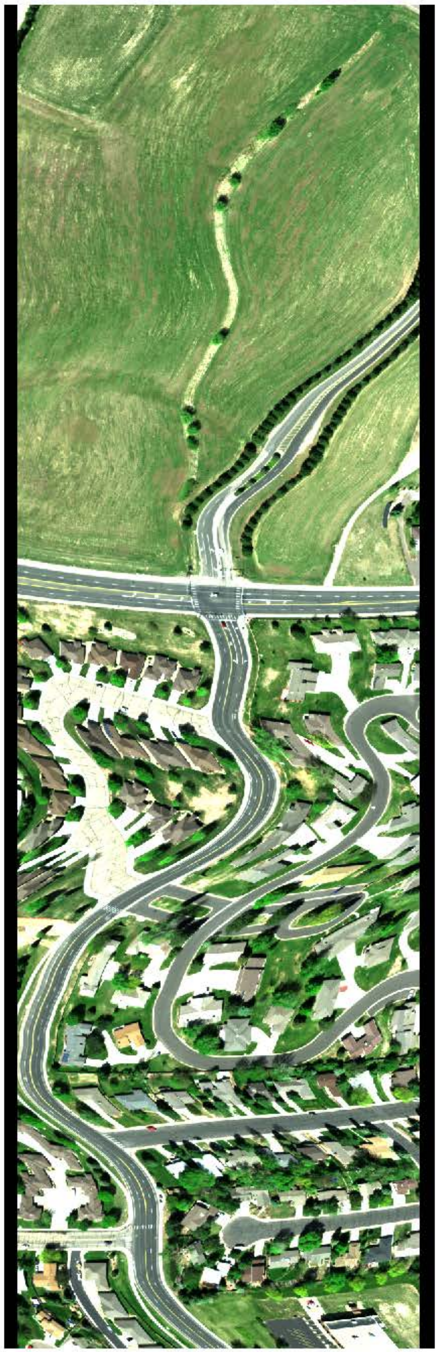


NIS Spatial Pixels

((Raw-DS-DPS-EPG-GC-BC)*FF)*RCC

NIS Level-1 Calibration Data Pro





NIS Spatial Pixels

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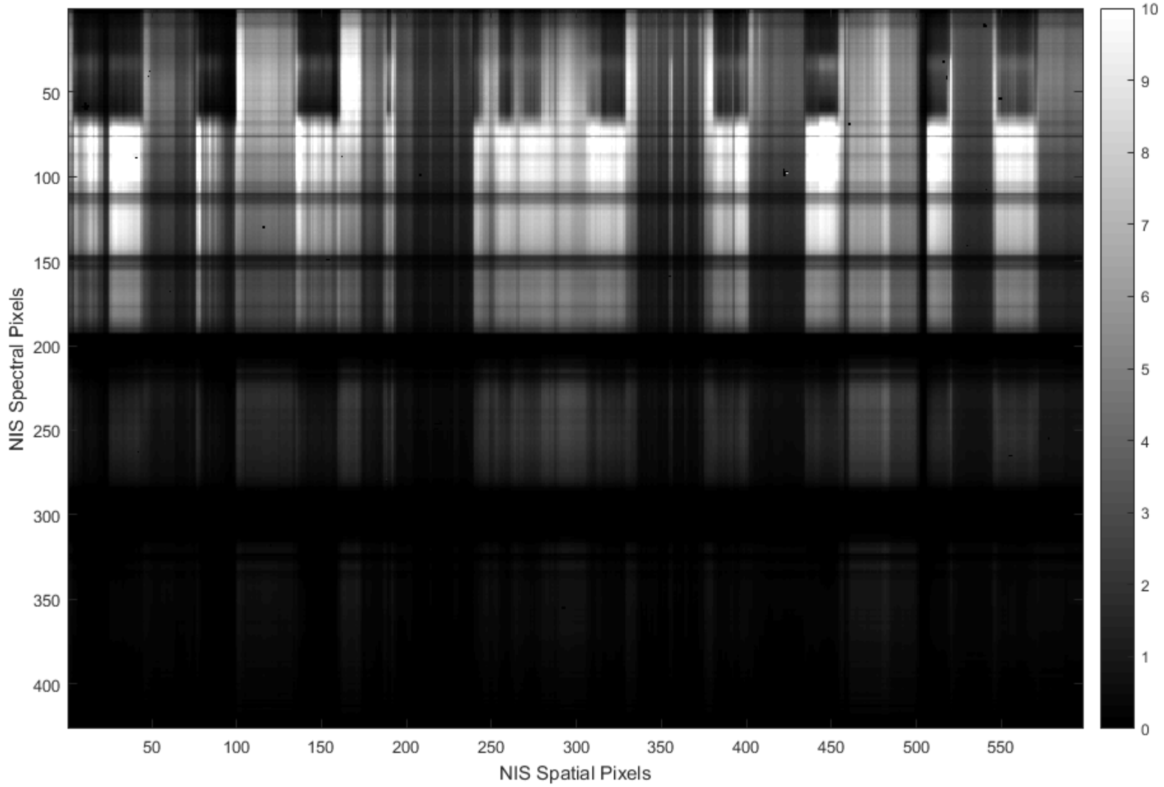
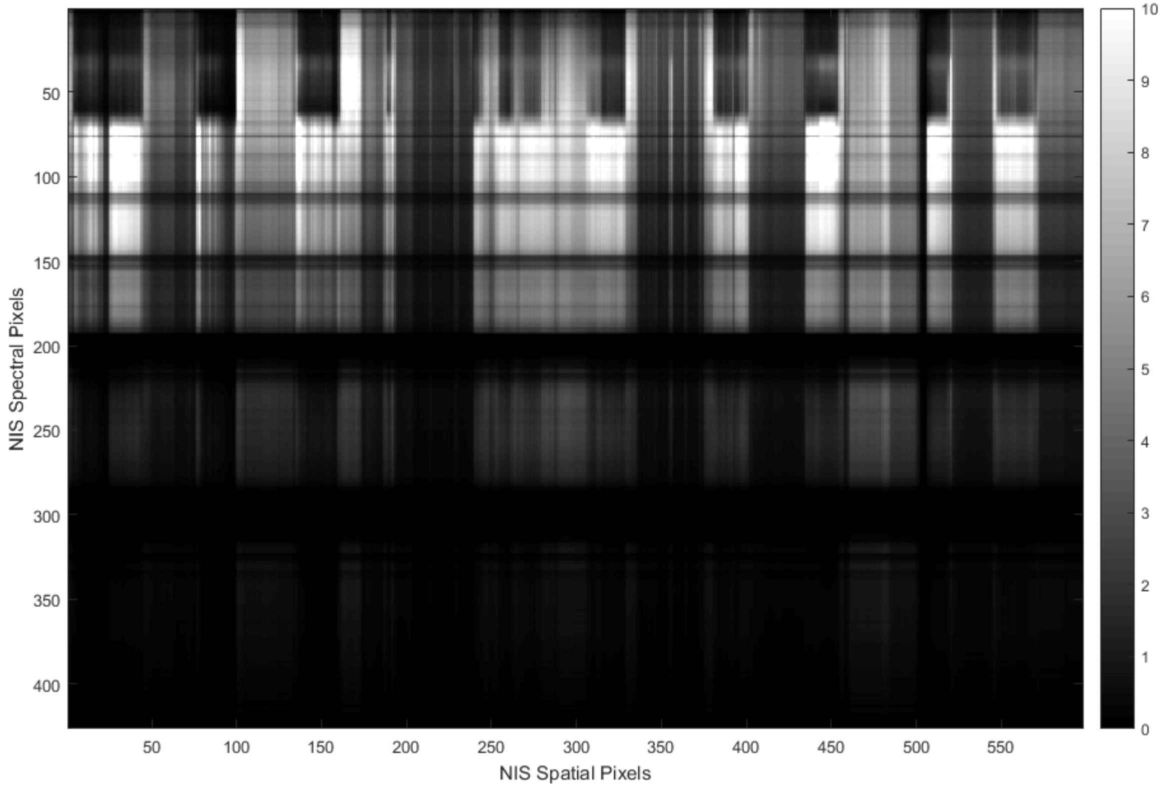
NIS Level-1 Calibration Data Proc



NIS Spatial Pixels

(((Raw-DS-DPS-EPG-GC-BC)*FF)*RCC)*BQES)[Trim]

NIS Level-1 Calibration Data Pro



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NIS Spatial Pixels

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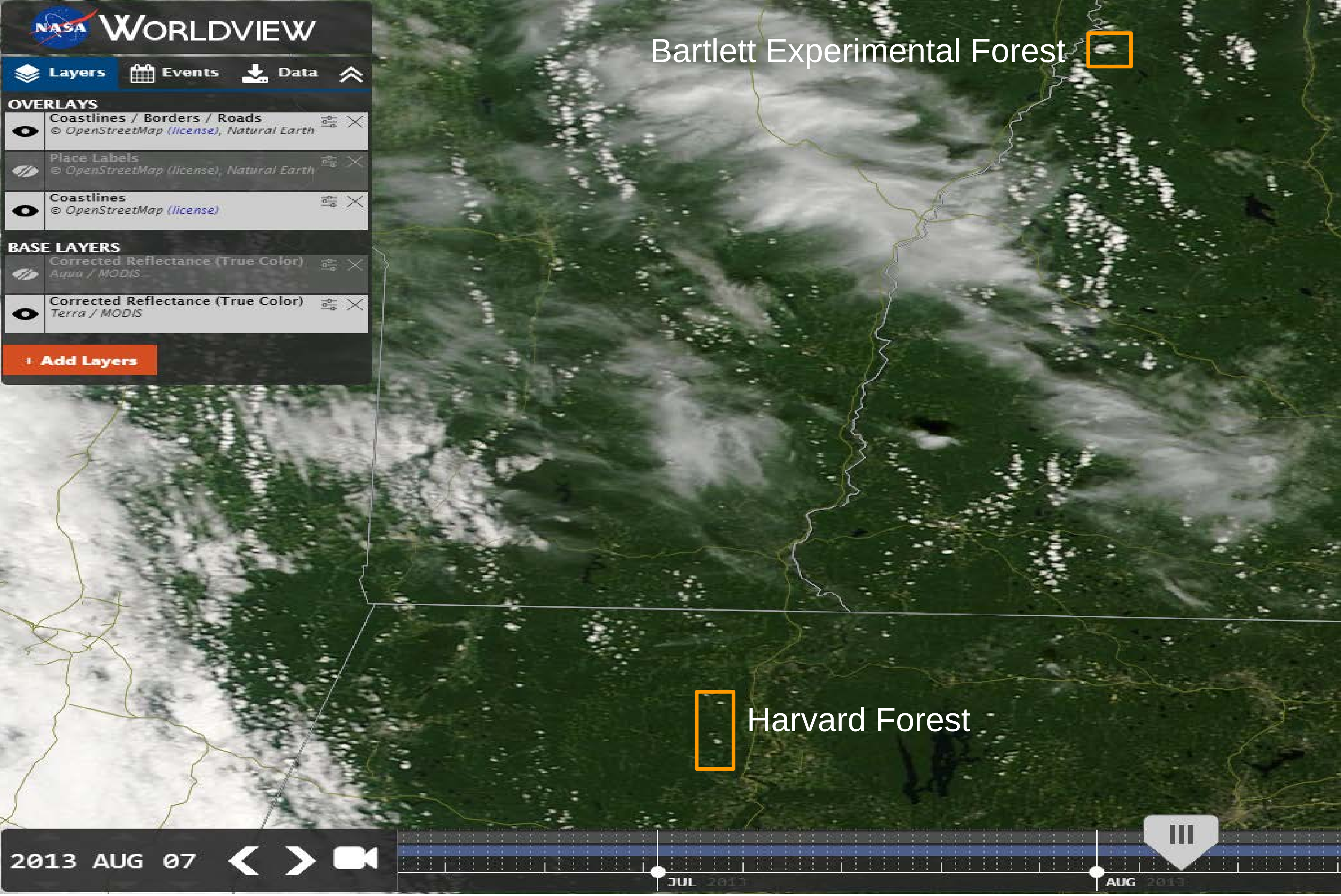
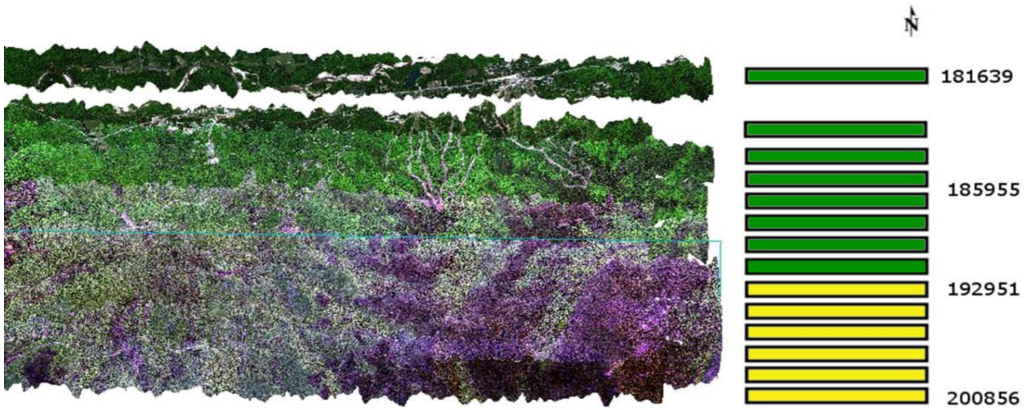
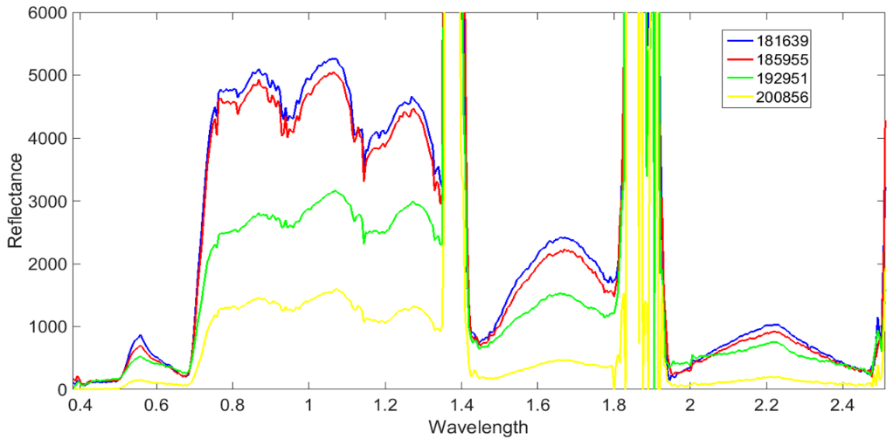

NASA
WORLDVIEW
Layers
Events
Data
OVERLAYS
Coastlines / Borders / Roads
© OpenStreetMap (license), Natural Earth
Place Labels
© OpenStreetMap (license), Natural Earth
Coastlines
© OpenStreetMap (license)
BASE LAYERS
Corrected Reflectance (True Color)
Aqua / MODIS
Corrected Reflectance (True Color)
Terra / MODIS
+ Add Layers
Bartlett Experimental Forest
Harvard Forest
2013 AUG 07
JUL 2013
AUG 2013

What about weather!!!

- Spectrometer uncertainty assumes weather conditions are good (cloud free)
- Weather is the highest source of uncertainty
- Even small buildup of cloud will have obvious impacts on reflectance
- Pay attention to the weather information provided in metadata of H5 files, KMLs, and PDFs





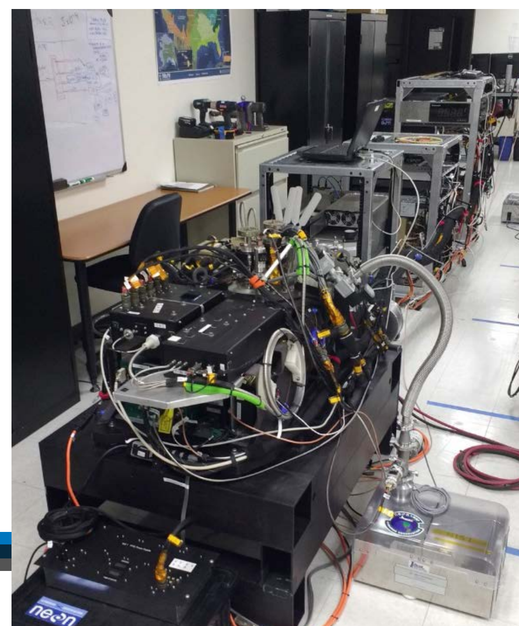
Airborne Observation Platform Team

<u>Flight Operations</u>

- Flight Architecture
- Support Logistics
- Payload installation
- Sensor operation
- Raw Data handling
- Flight notifications
- Permitting and FAA
- Payload maintenance

<u>Payload Development and Sensor Calibration</u>

- Payload integration
- Sensor calibration
- Sensor maintenance
- Verification testing
- Engineering support
- Payload software setup and versioning



<u>Data Processing & Algorithm Development</u>

- Algorithm development
- Data processing
  - LiDAR
  - NIS
  - Camera
- Implementation of lab calibration
- Flight Calibration
- Data QA/QC